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Microstrip Patch Antenna Design for 5G Applications at Sub-6 GHz Frequency Band

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ABSTRACT

An antenna plays an indispensable role in the field of radio engineering. The network between electric currents traversing in metal conductors and the radio waves circulation along space is designed with a transmitter or receiver.Microstrip patch antenna was originated in 1953. Although, due to their good features, i.e., low profile, inexpensive manufactures, lightweight and simple installation, they also became the interest area for the researcher. It started to awareness in 1970. A Microstrip patch antenna is tremendously serviceable in aircraft, spacecraft, satellite and wireless communication. The number of users substantially rises in wireless communication and the use of Microstrip Patch Antenna in the latest communication devices, i.e., smartphones, Wi-Fi routers, 5G mobile phones. In earlier time, enormous size antennas were utilized, but due to technological evolution, the large dimensions of the antennas were eradicated by the compact antenna. The study of researchers over the past decades indicates that most work on Microstrip patch antennas is now focused on how to achieve compact-sized and large bandwidth.This study offers an in-depth examination of antenna designs and their various feeding methodsand extended advanced research on various types of antennas and their upgrade approaches in order to achieve the compact size of the antenna for Sub-6 GHz for 5G using simple techniques such as patch and ground slot-loading.

***Key Terms*: Patch antenna, Radio Communication, 5G, Communication.**

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 both in transmitting and receiving electromagnetic waves[1][2].Recently, it has become an interesting topic for researchers and engineers due to the rapid expansion of technology in the zone of communication devices like the smart phone, radio sets, laptops with wireless connection and the Internet of Things,etc. As the numbers of users are exponential increase, it has become a serious problem with the 4G LTE technology regarding speed, large-detention for bandwidth-hungry video. This has shifted towards the 5th generation (5G) wireless communication. The primary goal of the 5G is to provide fleet transmission rate, tiny latency, tremendous traffic volume density, large signal bandwidth, better coverage and prime quality of service with low battery consumption at low cost[3]. The specification of 5Gis given in Table-1. 5G will support the number of users while operating over a large range of frequencies. There are various performance parameters of antenna used to analyze for the desirability of 5G.To enable the 5G, FCC divided the Frequency spectrum into three band i.e. high-band (millimeter Wave), middle-band (sub-6 GHz),lower band(up to 1 GHz)[4][5]. Table-2 and Table-3 show the frequency band for FR1 and FR2 in 5G. The low band offers good 5G coverage. Millimeter-Wave offers ultra-fast data rates above 2 Gbpswith large capacity and the midband offers a blend of both.The usage of the 5G Wave spectrum is adorable to achieve ultra-fast data rates. For the long-distance with high data rates, Sub-6 GHz is applicable for the built-up and the country side area.

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

S.No.	Parameter	5G
1	Peak data rates	20 Gbps
2	Latency	<1ms

3	Connectivity Density	1 million connection/K.m^2
4	Data traffic	50Exabyte/month
5	Available spectrum	30 GHz

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, LowerSMH, 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

With the introduction of Microstrip patch antennas, the design and fabrication of antennas has become more accessible over time.It first came up in 1953. The first experimental Microstrip patch antenna was developed by Munson and Howell [10] in the 1970s. In simple form,Microstrip Antennas have such a radiating patch on one side of a substrate and a ground plane on the other.[11], [12].It gives a better performance outcome as compared to the conventional antennas due to its additional benefits, such as ease of fabrication, low fabrication cost, less complexity, and straightforward integration with integrated microwave circuits. However, it has some drawbacks, such as low gain and low bandwidth. It can be remunerated by using a massive substrate with a lower value of dielectric constants

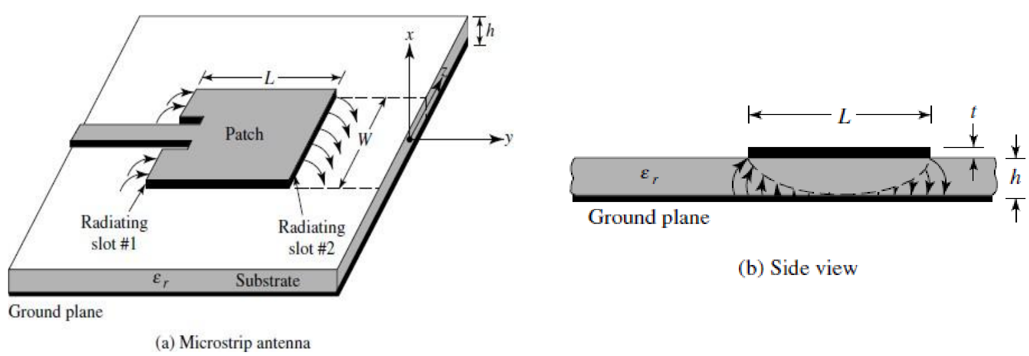


Fig.1. Microstrip antenna structure and its side view

In this article, the introduction of sub-6 GHz and progression of 5G are considered in section 1. Section 2 has considered the Microstrip patch antenna design equation using the transmission line model and its various feeding techniques. Section 3 described how compact sizes of the antenna are achieved by slot-loading and different review papers are analyzed. Section 4 is showing the conclusion part.

Rectangular patch antenna design:

In theFig.1 (a), the design conformation of the antenna comprises of a very fine metallic strip situated a small segment of a wavelength above a ground plane. Thedimension of the rectangular patch antenna controls the antenna frequency and input resistance. If the width of the antenna is too small, then it becomes a Microstrip line, not working as a radiator. Usually, The length of the patch for the basic TM_{10} mode incitement is somewhat slightly small to the λ/2, λwhere is the dielectric medium's wavelength, as to free-space wavelengthλ_0[11]. The ground plane is isolated by a dielectric material (known as substrate), as shown in Fig.1 (b)[12]. The gain of the patch antenna is in the middle of 5 dB to 6 dB and offers a 3-dB beam width in between 70° and 90°[12][13]. The property of the substrate material and the dimensions of the patch depend on the working frequency of operation. The proper selection of the substrate material with different permittivity and loss tangents can also enhance the antenna's performance. A substrate must be selected with low value of relative permittivity and low value of loss tangent to obtain high gain and reduce power losses**.**

Table4.shows various substrate materials along with their properties. The design parameters of the patch can be calculated by the following below equations[14][15].

Table 4.Properties of typical substrate materials [16]

Features	RO-4003	RO-4003	Fr4
Dielectric coefficient	2.2	3.4	4.4
Water absorption (percentage)	0.02	0.06	0.25
Loss tangent	0.0004	0,002	0.013
Tensile strength (MPa)	450	141	310
Surface resistivity (Mohm)	2 X 10^5	4.2 x 10^9	3 x 10^7
Volume resistivity (M-Ohm.cm)	2x10^7	1700 x 10^7	8 x10^7
Peel strength (N/nm)	2	1.05	9
Density (kg/m^3)	2200	1790	1850
Breakdown voltage	60 kV	-	55 kV

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

a) Height of the patch

$$h=\frac{0.3c}{2\Pi f\sqrt{\varepsilon_r}} (1)$$

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

b) Width (W) of the patch

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

W= the width is in millimeter (mm)

c) Effective dielectric constant (ε_{eff})

When constructing a rectangular patch antenna, the effective dielectric constant is an important factor to consider. When waves move from the radiating patch in the direction of the ground plane, they move through the air and, because of the fringing effect, some get away from the substrate. The value of the dielectric materials is different for different mediums. Because the electromagnetic wave travels, the value of the effective dielectric constant must be calculated. The effective dielectric constant may be computed using the equation below

$$.\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2} (3)$$

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

d) Patch length

Length expansion is the extra length at the end of the patch due to the fringing field along its width. By using the following equation, the length expansion is calculated.

$$\Delta L = 0.412\frac{[\varepsilon_{eff}+0.3][\frac{h}{w}+0.264]}{[\varepsilon_{eff}-0.258][\frac{h}{w}+0.8]} (4)$$

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

e) Effective patch length (L_{eff})

The effective path length is calculated by using theformula.

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{eff}}} (5)$$

Where ε_{eff} = Effective dielectric constant

f) Actual length (L) of the patch

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

Where $L_{eff=}$ Effective patch length

g) 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.

Feeding techniques of Microstrip patch antenna

a) Feeding methods enhance different properties of antenna-like bandwidth, radiation pattern, gain, impedance, and polarization. The electromagnetic waves are directed via a feed that travels from the source to the patch's bottom. Some of this energy escapes into space through the patch's border. The feeding may be classified into two types: contacting and non-contacting. The power of the input radio frequency is direct supplied to the patch by an attach section, such as a Microstrip line, in the contacting technique. While in non-contacting method, generally considered an indirect one, electromagnetic field coupling moves the power in the middle of the Microstrip line and the radiating patch. The well-known feeding techniques working in the Microstrip patch antenna are the co-axial feed, Microstrip line, aperture, and proximity coupling techniques. An outline of each feeding method is given in this section.

b) Microstrip Line Feed

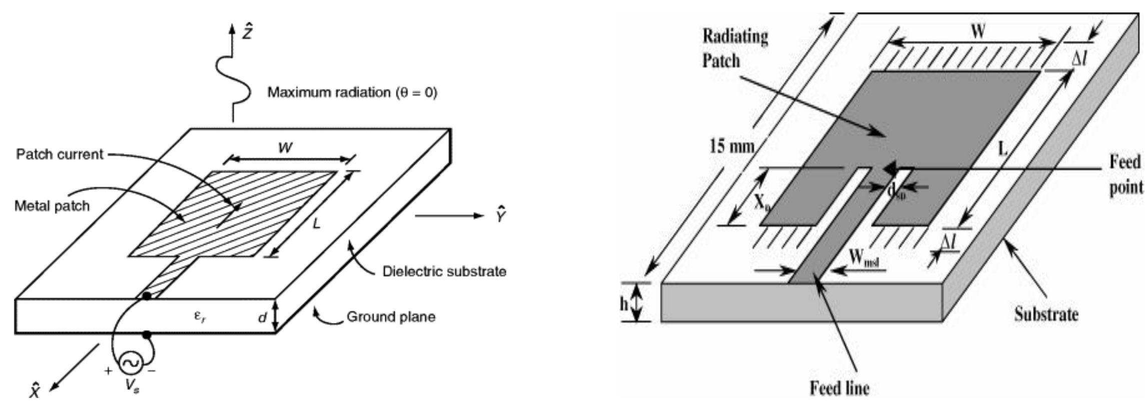


Fig.2. (a) Microstrip Antenna using Microstrip Line. (b) Microstrip Antenna using inset fed

The side of the patch antenna is directly attached to the conducting strip[19]. This grouping provides a planar construction. Generally, the width of the conducting element is less than the patch antenna. Because of these disadvantages, big-size arrays may be created by using edge-fed patches.The feed line's radiation is a source of insufficiency, leading to a cross-polar plane growth. This is performed by perfectly controlling the inset positions shown in Fig (b). For the proper good impedance matching and without the requirement of extra matching components, the feed position of the patch may also have a cut into the patch. This is attained by appropriately managing position of inset. This feeding method is uncomplicated because of the simple fabrication and ease in modeling and good impedance matching.

c) Coaxial Probe Feed

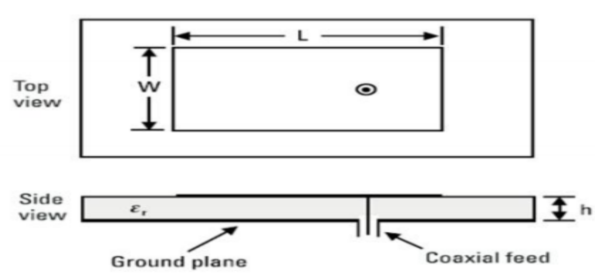


Fig.3. Coaxial Probe Feed

The co-axial Probe Feed technique is simple to construct and produces minimal spurious radiation.. The outside conductor of a co-axial connector is connected in the ground plane. However, the coaxial's inner side is stretched over the dielectric and connected to the antenna's radiating component. The great advantage of these methods is that they can be positioned at any preferred location of the inner part of the patch for the proper matching of input impedance. However, its big demerits are that it gives less bandwidth and insufficient radiation. This feeding arrangement makes the asymmetrical arrangement which is not entirely planar. For thick substrates, if the co-axial feed length increases, it gives undesired radiation, making the input impedance more inductive.

d) Proximity Coupled (Electromagnetically) Microstrip Feed Technique

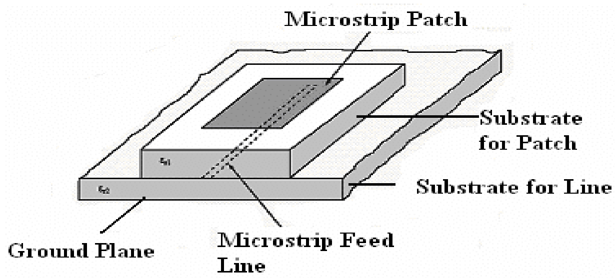


Fig.4. Microstrip Antenna fed by Aperture Coupled Microstrip Feed

This arrangement shows a non-contacting method of feeding. Electromagnetic coupling techniques are another name for proximity-coupled feed methods.It employed two dielectric substrates, with the feeding line running through the centre of each and the radiating patch on the higher of the two levels, as illustrated in Fig.4. Two dielectric layers are used in this method. One layer is a radiating patch, and in the lower layer a ground layer is created on the behind. [19]. With the help of the common ground plane, two dielectric substrates are isolated from each other. The patch is electromagnetically connected to the Microstrip line, which is located on the bottom substrate, through a slot aperture in the common ground plane. By proper selection of the dimension of the slot which can enhance the performance parameter. Radiation from the open section of the feed line does not interfere with the patch's radiation pattern because of the shielding effect of the ground structure.[18].

Aperture Coupled Microstrip Feed

In this feeding method [14], the radiating patch and feed line are coupled by a hole or slot cut in the ground surface. Coupling variation depends on the dimension of the aperture into the ground plane. This will change the performance parameterize result, i.e., bandwidths and return losses. The coupling slot is generally centered below the patch. Cross-polarization has been enhanced by the uniform configuration. The aperture can be either non-resonant or resonant. For better performance parameter results, two unlike substrate materials can be selected for the two layers.

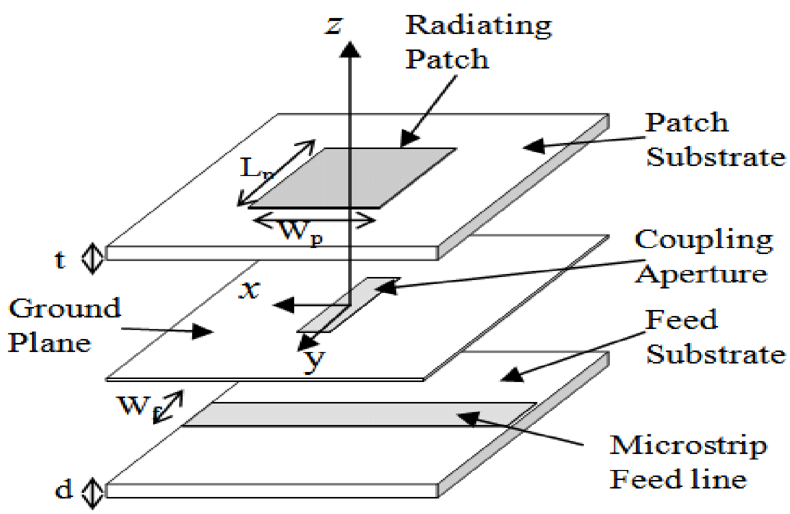


Fig.5. Coupled Microstrip Feed method

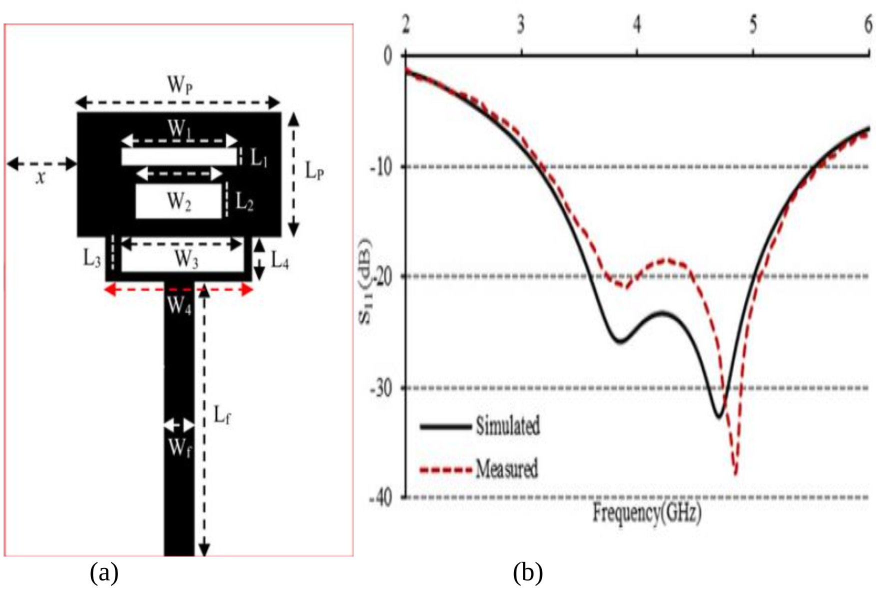
Table5: A comparison tablebetween different methods of feeding [20]

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

Review of Compact Microstrip patch antenna for sub 6Ghz

Day by day, technologies in communication are developing. The devices used in these technologies become small. For increasing the bandwidth while not increasing the size, various methods like Stacked Shorted Patch, Shorted Patch, Slotted Ground Plane method, and Slot-Loading method are used by manufacturers.This article examines how the Slot-Loading Technique and the Slotted Ground Plane Technique are utilized to minimize antenna size.

a) Compactness is achieved via the slot-loading approach.Using a slot on the patch, the current path length on the patch increases, increasing the bandwidth and reducing the size.The antenna structure is 20 × 30 × 1.5.the designed antenna structure comprises three slots on the patch arranged on a steeped rectangular radiating portion with three slots and a fragmentary ground plane. It is printed on both sides of an FR4 dielectric substrate. In this structure, slots couples with the ground plane to achieve good gain, efficiency, and large bandwidth, i.e.,3.15–5.55 GHz and omnidirectional pattern to cover sub6 GHz bands, WLAN, Wi-Fi, and LTE bands[21]



(a) (b)

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

b) Another review paper of slot-loaded Microstrip antennas is studied [22]. Results show that the compact size and large bandwidth are achieved by using three slots on the patch. The size of the antenna is 50x30mm^2. The antenna is fabricated on Rogers 5880 substrate having a permittivity of 2.2 and a thickness of 1.57 mm. The antenna resonates on two frequencies at 3 GHz and 3.3 GHz, and measured results indicate that the antenna gain is 4.7 dB at 3 GHz, and at 3.05 GHz, the reflection coefficient is - 22 dB and 3.3 GHz, it is -16 dB.

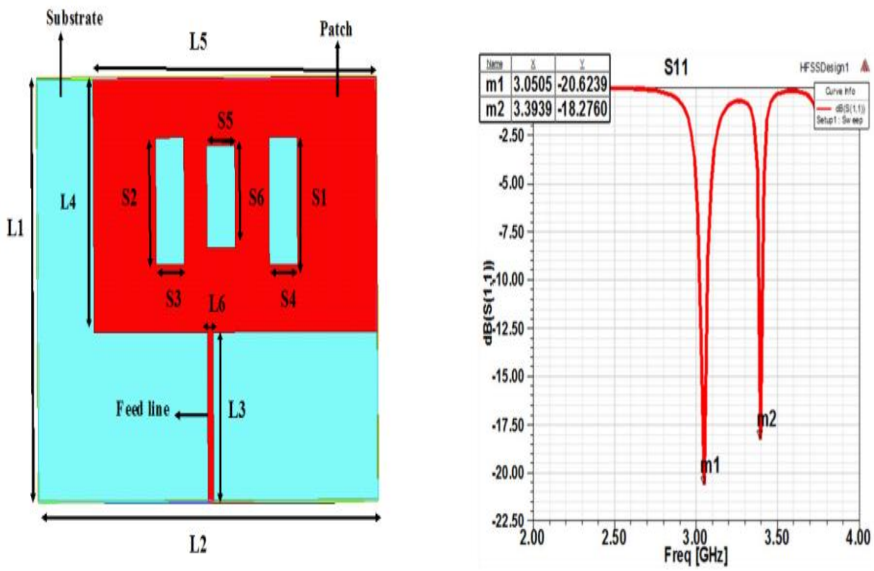
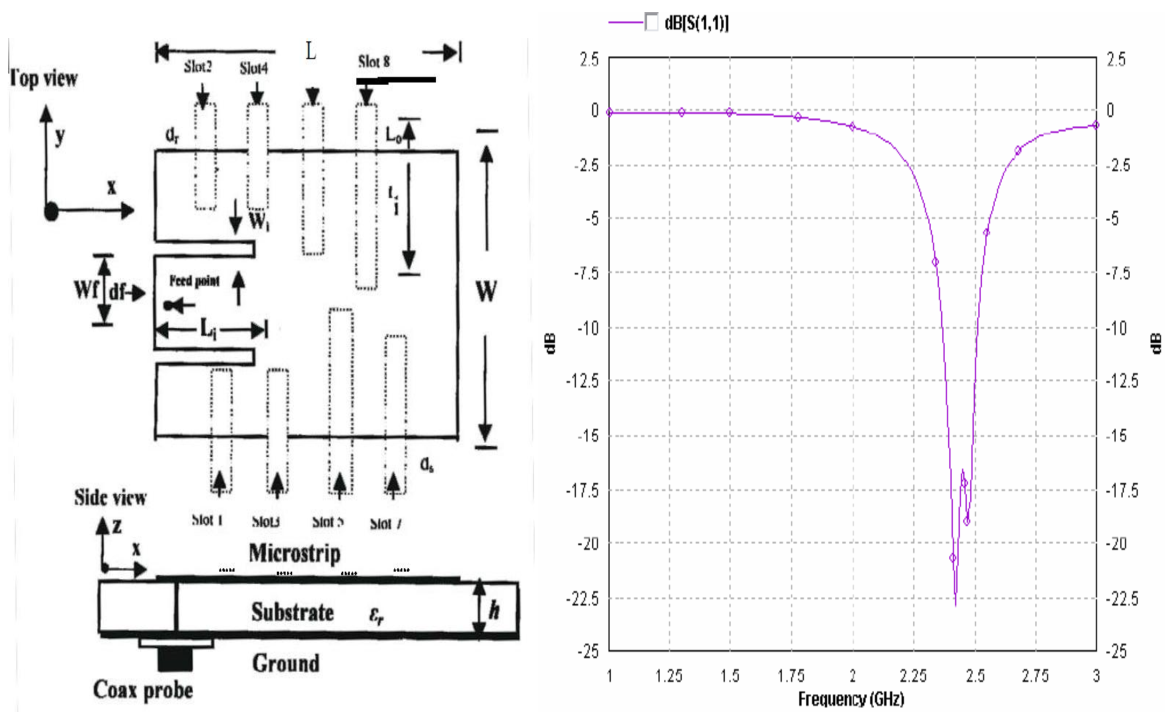


Fig.7. (a) antenna Structure, and b) The return loss of the antenna vs. frequency[22]

c) In another study, by using four slots in the ground plane to enlarge the excited plane current in the ground plane. This will enhance the performance of the antenna and also reduce its size[23].



(a) (b)

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

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

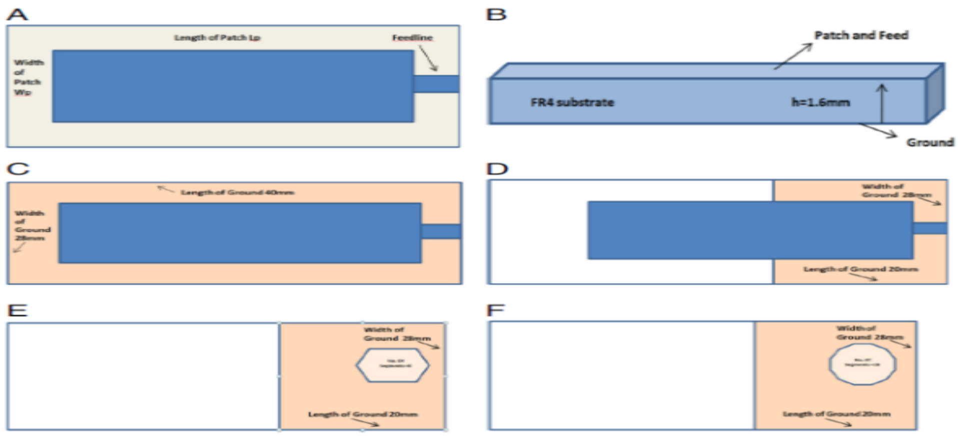


Fig.9 (a) Antenna structure

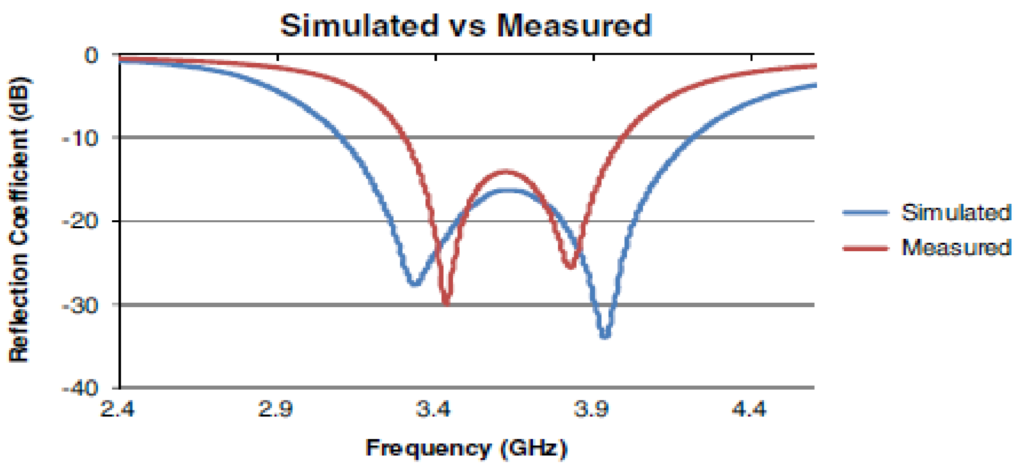
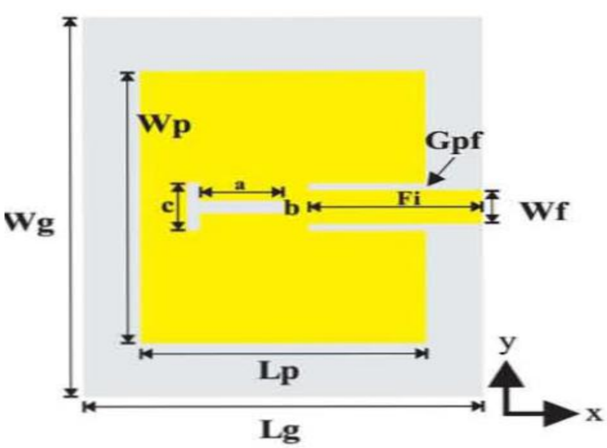
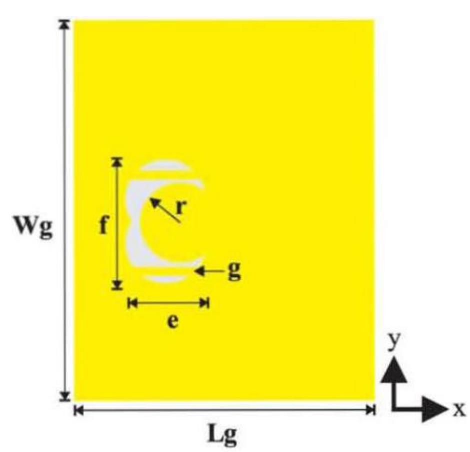


Fig.9(b) Return loss of the antenna vs. frequency[24]

e) In the other study antenna, the patch has been loaded by a T slot. This increases the radiation properties of the antenna. The T-slot initiates impedance into the design, which, when perfectly placed, gives the antenna's radiation attributes. The ground structure of the antenna has specific C slot structures. By using the slotted ground plane Microstrip patch antenna use for the ISM band applications. The antenna resonates at 4.96 GHz and is acceptable for sub 6 GHz wireless communications[25].



(a)



(b)

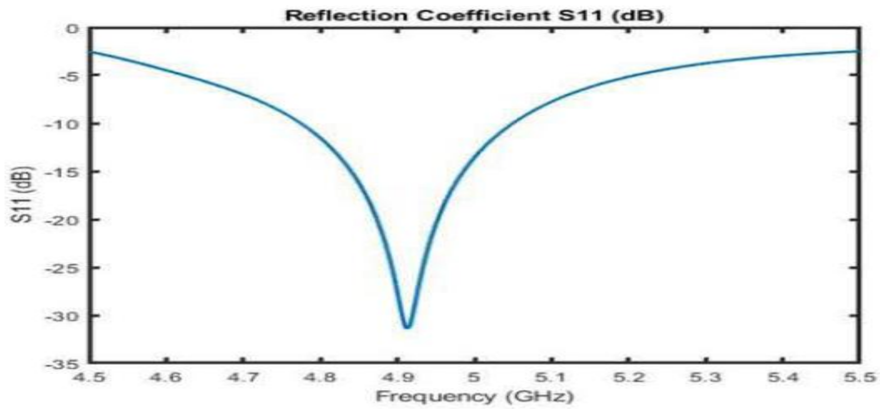


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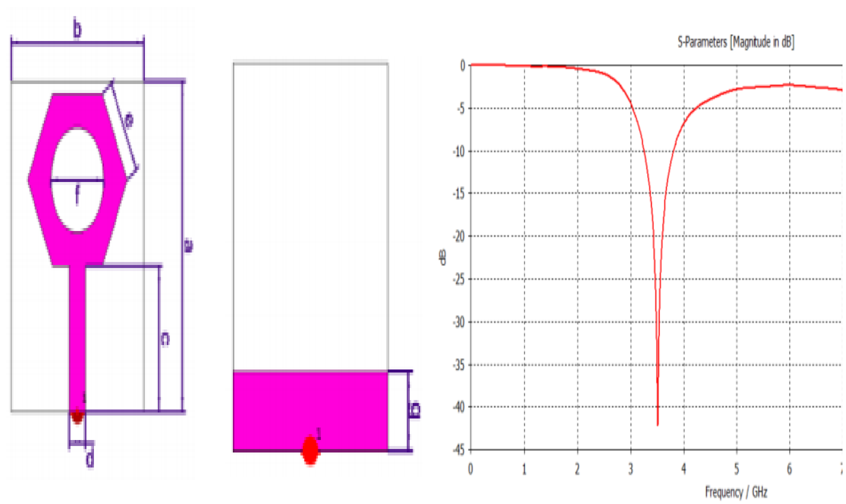
Fig.10. (a) Top view Antenna (b) Ground plane of Antenna (c)Reflection coefficient (S11) of the antenna[25]

f) In another study[26], a slotted hexagonal Microstrip patch antenna has been studied. The size of the antenna is small by cutting a hexagonal-figure patch and the circular hole are loaded between the patch. The antenna resonates at frequency 3.5 GHz, and its results include reflection co-efficient of -42.18dB and good bandwidth of 550MHz, 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]

Table6: Comparison analysis of different types of antennas for sub-6 GHz applications

Ref	MPA Configuration	Feeding mechanism	Material	Permittivity	Freq.	Gain (dbi)	Return loss	Application
[26]	Slotted hexagonal patch antenna	Microstrip line	Fr4	4.4	3.5	3.93	-42.18	Wireless application
[27]	Bus shaped Microstrip patch antenna	Inset feed	PET	3	5.3	5.9	-26.76	Wireless application
[28]	Compact Microstrip patch antenna	Coaxial feed	RT-duroid	2.33	3.5	6	-24.51	WiMax
[29]	Microstrip Patch array	Microstrip line	Rogers Duroid RT-5880	2.2	3.8	13.2	NA	WiMax and UAV applications
[30]	Multiband	Microstrip	Fr4	4.4	0.77,	1.1,	-20.2,-14.5,	Digital

	inverted E and U-shaped compact antenna	line			1.43, 2.13, 3.48, 3.84, 5.17, and 6	1.3, 1.1, 1.6, 1.7, 1.8, and 2.2	-11.5, -15.5, -16.2, -10.5, -16.2	Broadcasting, Medical telemetry, WLAN, WiMAX, Sub 6 GHz 5G
[31]	Microstrip patch antenna	Microstrip line	Rogers RT-5880 Substrate	2.2	NA	NA	−18.2 dB	WiMax

CONCLUSIONS

An evaluation of sub-6GHz antennas for 5G communication has been completed. The researchers are more concerned with the antenna's design along with its performance specifications. It discovered that the form and placement of the slots on the patch or the ground can impact the gain, bandwidth, and radiation losses.In order to make 5G antennas more compact, a novel slot loading mechanism on the patch or ground was utilized. The resonance frequency is reduced as a result, and the antenna dimensions are reduced.

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