زانكۆی سەلاحەدین-هەولێر

Salahaddin University-Erbil

College of Education

Design and Simulation of Microstrip Patch Antenna Array for 5G Application

Research project

the Submitted to department of physics in partial fulfillment of the requirements for the degree of B.Sc. in physics

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا ۖ إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيم

صدق الله العظيم

سورة البقرة - الآية 32

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Supervisor Certificate

This research project has been written under my supervision and has been submitted for the award of the degree of BSc. in (Physics).

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Date 8/ 4 /2024

I confirm that all requirements have been completed.

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Abstract

The fifth generation (5G) applications require the components of the wireless communication systems to operate at large frequency ranges. This is to increase the data rate capability and reduce the network traffic in the systems. Therefore, the main purpose in this project is to propose and design a 4×1 microstrip patch antenna array with frequency reconfigurability feature usingthe Computer Simulation Technology (CST) microwave studio. 4×1 microstrip array, the proposed microstrip array has capability to resonate at 28 GHz. The antenna array gain is more than 13dBi over the operating frequency range. The radiation pattern is directive with very low side lobe level at both the E- and H- planes. The proposed microstrip antenna is low profile and compact in which it may be of interest in some 5G applications.

CHAPTER ONE

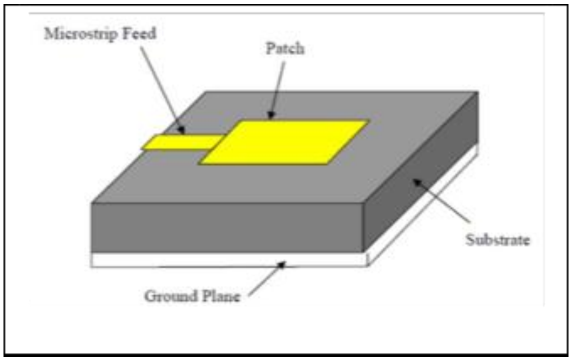
1.1 Introduction:

The standardization of 5G is being developed with a first deployment planned for the moment in 2020.4G cannot meet current requirements such as congestion or the reduction of energy consumption. That is why the world is focuses on 5G. The 5G which will probably still see a large increase in data volumes exchanged .And it uses a millimeter bands. Millimeter band is a band of spectrum from 26GHz to 300GHz.It is also known as extremely high frequency (EHF) or veryhigh frequency(VHF).It is a undeveloped band of spectrum that can be used in a broad range of products services like high speed, point to point WLANS etc. In 5G the allocation of data rate is up to 10Gbps.As it uses low propagation capacity with implementation of small cell radio transmitter. It is used to identify several trends of 5G specifications. The main aim of this paper is to design and simulation of rectangular patch antenna arrays with micro strip and coaxial feeding techniques and generate resonant frequency at 28GHz for future 5G applications.The simulation results shows that 2*2 antenna array fed by coaxial line is better than 4*1 antenna array fed by micro strip line. Gain of 2*2 and 4*1 antenna array is 12.56db and 10.81db.bandwidth of 2*2 and 4*1 antenna array is 0.9GHz and 1GHz.Return losses of 2*2 and 4*1 antenna array is -49.56db and -12.52dB.(Aboshosha, El-Mashade, & Hegazy, 2021), issue to the use of high-frequency bands. This issue can be overcome by using a high gain Multiband microstrip patch antenna (MMPA) has several benefits, such as low cost, low profile, lightweight, easy manufacturing, and including conformance. To these feature's benefits, MMPA has become an essential part of today's wireless communication sector. On the other hand, poor performance occurs due to narrow bandwidth, low gain, low capacity, etc. In some cases, the aforementioned variables impose restrictions on antenna applications. In the nextgeneration wireless communication (5G) path loss will become a major antenna. The fundamental goal of the research is to design a high-gain MMPA array antenna. An

MMPA is designed and simulated at CST Microwave Studio, the proposed antenna covers the following frequency bands such are 26.305 GHz, 29.125 GHz, and 37.78 GHz respectively. (Islam et al., 2022), This paper presents design of an efficient microstrip antenna array for 5G communication systems. The antenna operates at 28 GHz and it is formed of 16 elements of rectangular patches arranged in a linear configuration. The single element has gap-coupled feeder and the antenna is designed on low-loss Teflon based RT/duroid 5880 substrate with dielectric constant of 2.2 and substrate thickness of 0.381 mm. (Saada, Skaik, & Alhalabi, 2017), The purpose of this project is developing, designing of the Microstrip Patch antenna for 5G applications. The study made in project focuses on simulation of micro-strip patch antenna using CST software and studying the radiation pattern and radiation pattern parameters and comparing with specifications / requirements. The microstrip feed method is used in this project. With development of 5G network antennas, the two basic thing kept in mind while designing antenna is MIMO and Beam steering. Array antenna helps you provide both in compare to single path antenna (Sarade, Ruikar, & Bhaldar, 2020), our goal is to analyze the design of four elements 28GHz microstrip patch array antenna for future 5G mobile phone applications. The designed antenna can be implemented using low cost FR-4 substrates and can maintain good performance in terms of gain and efficiency. Additionally, the simulated results demonstrate that it has S11 response of less than -10 dB in the 22-34 GHz frequency range(EL_Mashade & Hegazy, 2018),A modified T-shaped antenna array design is presented for V-band applications. A prototype of 1x4 T-shaped antenna array is designed. The single element of the array comprises of a T-shaped patch. The array antenna presented in this paper are optimized to minimize the cost and complexity. It is observed that the proposed antenna offers V band characteristics from 53.78GHz to 62.17GHz. The measured results of the 1x4 array antenna shows the low return loss of (s11=- 24.1024dB) and a high gain of 5.1760e+000(El Hasnaoui & Mazri, 2020), A dual-band dual-linear polarization reflectarray configuration is developed for future 5G cellular applications. A single layer unit cell including two pairs of miniaturized fractal patches is designed to operate at two distinct frequencies within the Ka-band (27/32 GHz), in a dual-polarization mode. An indepth analysis of the unit cell behavior is carried out, to demonstrate the total independence between the designed frequency bands and polarizations. The proposed configuration offers a very simply and thin structure, small unit cell sizes, and low losses, while leading to an independent optimization of the phase at each frequency and polarization.(Costanzo, Venneri, Borgia, & Di Massa, 2020)

1.2 Type of Microstrip patch antenna:

Microstrip antennas received considerable attention starting in the 1970s, although the idea of a microstrip antenna can be traced to 1953 and a patent in 1955, Microstrip antennas, as shown in Figure,(Alsager, 2011)



Often microstrip antennas are also referred to as patch antennas. The radiating elements and the feed lines are usually photoetched on the dielectric substrate. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. These and others are illustrated in Figure1.1(Alsager, 2011)

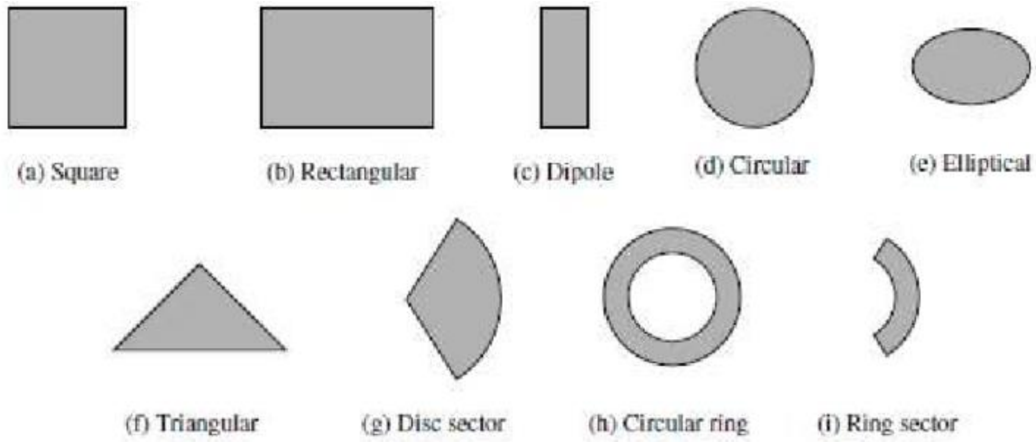


Figure1.1 Representative shapes of microstrip patch elements.

1.3 Type of feeding:

There are many configurations that can be used to feed microstrip antennas. The four most popular are the microstrip line, coaxial probe, aperture coupling, and proximity coupling, These are displayed in Figure1.2(Kumar & Sharma, 2019)

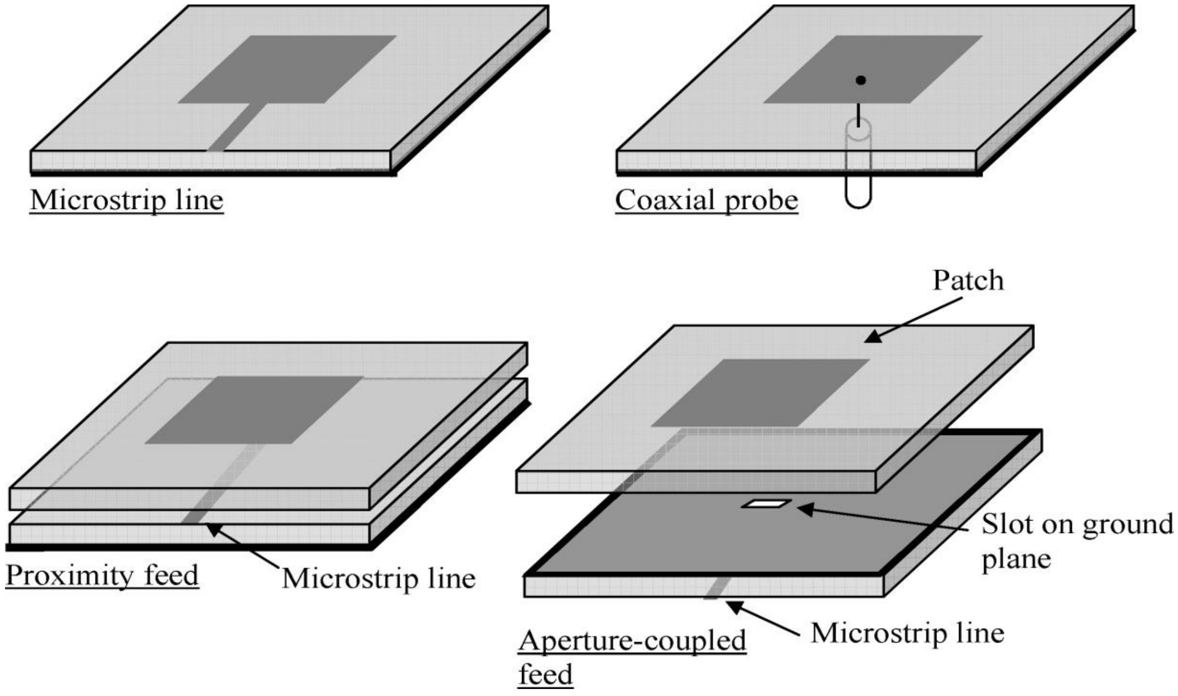
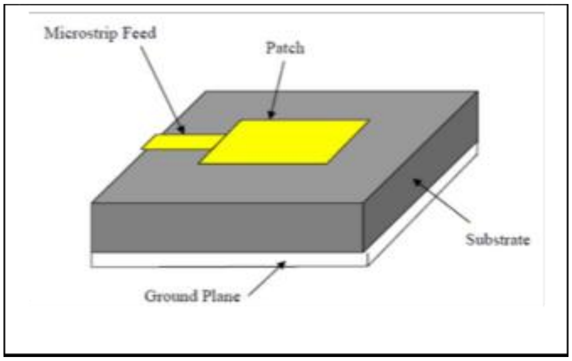


Figure1.2Typical feeds for microstrip antennas.

1. Microstrip line:

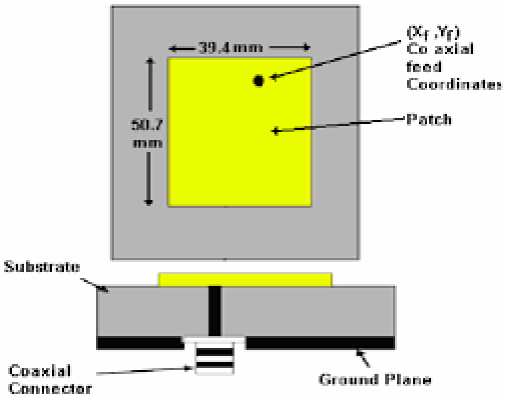
A conducting strip is connected to the edge of the patch. The feed can be etched on the substrate.



2. Coaxial probe:

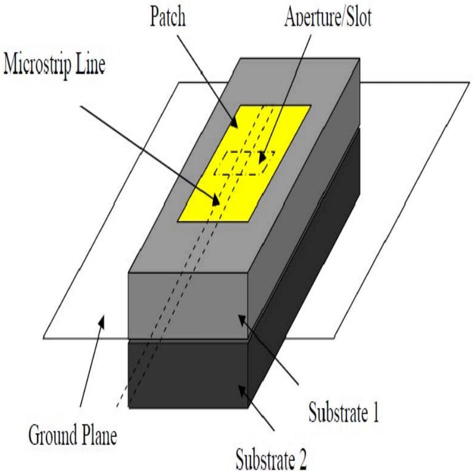
The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas.

The center conductor of the coaxial connecter is soldered to the patch.



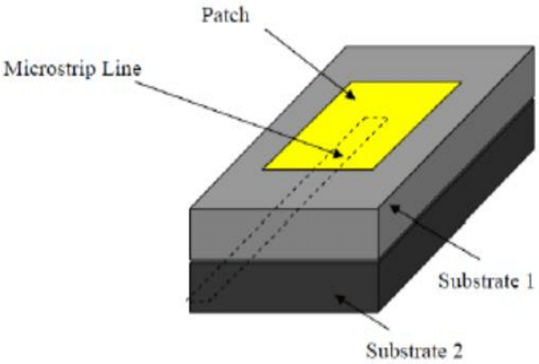
3.Aperture coupling:

is the most difficult of all four to fabricate and it also has narrow bandwidth. However, it is somewhat easier to model and has moderate spurious radiation. The aperture coupling consists of two substrates separated by a ground plane.

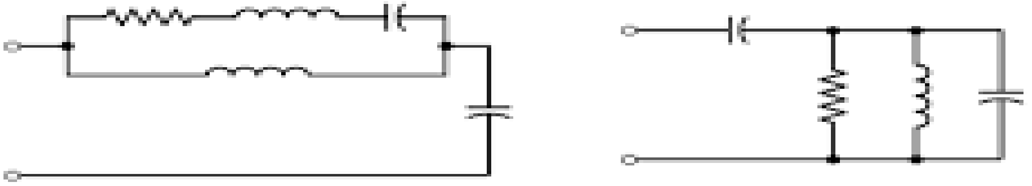


4. Proximity coupling:

Proximity coupled feed technique is also called as the electromagnetic coupling scheme. Two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate.



(a) Microstrip line (b) Probe



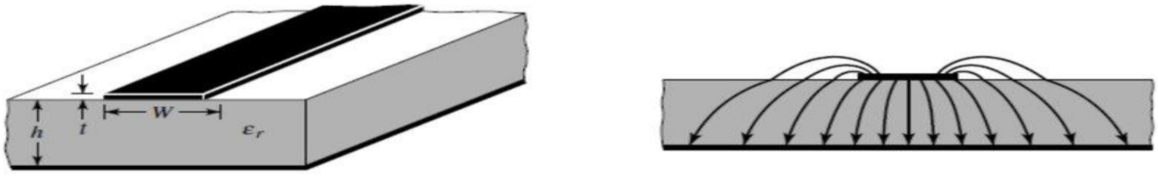
(c) Aperture-coupled (d) Proximity-coupled

Figure 1.3 Equivalent circuits for typical feeds of Figure1.2

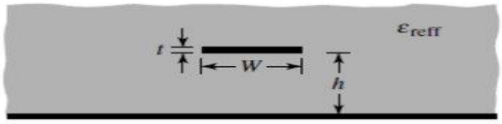
CHAPTER TWO

2.1 Theory:

It was indicated earlier that the transmission-line model is the easiest of all but it yields the least accurate results and it lacks the versatility. However, it does shed some physical insight. using the cavity model, a rectangular microstrip antenna can be represented as an array of two radiating narrow apertures (slots), each of width W and height h, separated by a distance L. Basically the transmission-line model represents the microstrip antenna by two slots, separated by a low-impedance Zc transmission line of length L. (Balanis, 2016)



(a) Microstrip line (b) Electric field lines



(c) Effective dielectric constant

Figure 2.1 Microstrip line and its electric field lines, and effective dielectric constant geometry

2.1A:Fringing Effects:

Because the dimensions of the patch are finite along the length and width, the fields at the edges of the patch undergo fringing. This is illustrated along the length in Figures 2.1(a,b) for the two radiating slots of the microstrip antenna. The same applies along the width. The amount of fringing is a function of the dimensions of the patch and the height of the substrate. For the principal E-plane (xy-plane) fringing is a function of the ratio of the length of the patch L to the height h of the substrate (L/h) and the dielectric constant εr of the substrate. Since for microstrip antennas $L / h \gg 1$, fringing is reduced; however, it must be taken into account because it influences the resonant frequency of the antenna. The same applies for the width. For a microstrip line shown in Figure 2.1(a), typical electric field lines are shown in Figure 2.1(b). This is a nonhomogeneous line of two dielectrics; typically the substrate and air. As can be seen, most of the electric field lines reside in the substrate and parts of some lines exist in air. As $W / h \gg 1$ and $\varepsilon_r \gg 1$, the electric field lines concentrate mostly in the substrate. Fringing in this case makes the microstrip line look wider electrically compared to its physical dimensions. Since some of the waves travel in the substrate and some in air, an effective dielectric constant $\varepsilon_{reff}$is introduced to account for fringing and the wave propagation in the line. To introduce the effective dielectric constant, let us assume that the center conductor of the microstrip line with its original dimensions and height above the ground plane is embedded into one dielectric, as shown in Figure 2.1(c). The effective dielectric constant is defined as the dielectric constant of the uniform dielectric material so that the line of Figure 2.1(c) has identical electrical characteristics, particularly propagation constant, as the actual line of Figure 2.1(a). For a line with air above the substrate, the effective dielectric constant has values in the range of $1 < \varepsilon_{reff} < \varepsilon r$. For most applications where the dielectric constant of the substrate is much greater than unity ($\varepsilon_r \gg 1$), the value of ε_{reff} will be closer to the value of the actual dielectric constant $\varepsilon_r$of the substrate. The effective dielectric constant is also a function of frequency. As the frequency of operation increases, most of the electric field lines concentrate in the substrate. Therefore the microstrip line behaves more like a homogeneous line of one dielectric (only the substrate), and the effective dielectric constant approaches the value of the dielectric constant of the substrate. Typical variations, as a function of frequency, of the effective dielectric constant for a microstrip line with three different substrates are shown in Figure 2.2. For low frequencies the effective dielectric constant is essentially constant. At intermediate frequencies its values begin to monotonically increase and eventually approach the values of the dielectric constant of the substrate. The initial values (at low frequencies) of the effective dielectric constant are referred to as the static values, and they are given by:(Balanis, 2016)

$$W / h > 1$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}} \qquad (2.1)$$

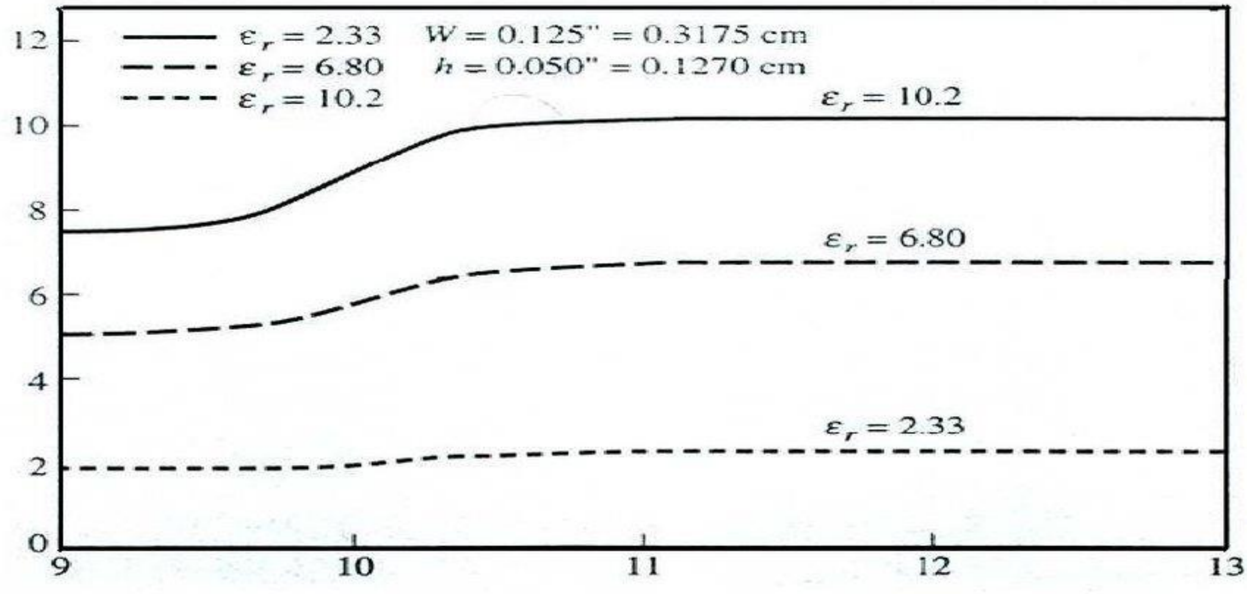
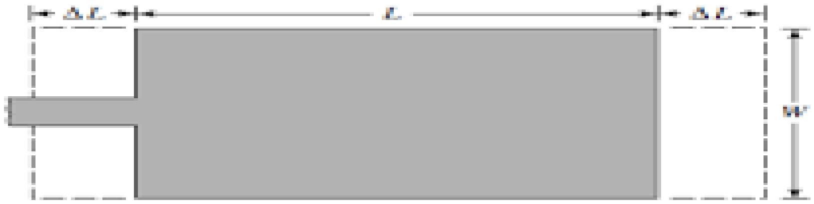


Figure 2.2 Effective dielectric constant versus frequency for typical substrates.



(a) Top view

(b) Side view

Figure 2.3 Physical and effective lengths of rectangular microstrip patch.

2.1B. Effective Length, Resonant Frequency, and Effective Width

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. For the principal E-plane (xy-plane), this is demonstrated in Figure 2.3 where the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant $\varepsilon_{reff}$and the width-to-height ratio (W/h). A very popular and practical approximate relation for the normalized extension of the length is

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

(2.2)

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now ($L \ = \ \lambda \,/\, 2$ for dominant TM010 mode with no fringing)

$$L_{eff} = L + 2\Delta L$$

(2.3)

For the dominant TM010 mode, the resonant frequency of the microstrip antenna is a function of its length. Usually it is given by

$$(fr)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_\circ\, \varepsilon_\circ}} = \frac{\vartheta_\circ}{2L\sqrt{\varepsilon_r}}$$

(2.4)

where $\upsilon 0$ is the speed of light in free space. Since (2.4) does not account for fringing, it must be modified to include edge effects and should be computed using

$$(frc)_{010} = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\sqrt{\mu_\circ\varepsilon_\circ}} = \frac{1}{2(L+2\Delta L)\sqrt{\varepsilon_{reff}}\sqrt{\mu_\circ\varepsilon_\circ}} = q\,\frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_\circ\varepsilon_\circ}} = q\,\frac{\vartheta_\circ}{2L\sqrt{\varepsilon_r}}$$

(2.5)

Where

$$q = \frac{(frc)_{010}}{(fr)_{010}}$$

(2.5a)

The q factor is referred to as the fringe factor (length reduction factor). As the substrate height increases, fringing also increases and leads to larger separations between the radiating edges and lower resonant frequencies. The designed resonant frequency, based on fringing, is lower as the patch looks longer, as indicated in Figure 2.3. The resonant frequency decrease due to fringing is usually 2–6%.(Balanis, 2016)

2.1C.Design:

Based on the simplified formulation that has been described, a design procedure is outlined which leads to practical designs of rectangular microstrip antennas. The procedure assumes that the specified information includes the dielectric constant of the substrate (ε_r), the resonant frequency (f_r), and the height of the substrate h. The procedure is as follows:

Specify:

εr, fr (in Hz), and h

Determine:

W, L

Design procedure:

1. For an efficient radiator, a practical width that leads to good radiation efficiencies is

$$W = \frac{1}{2fr\sqrt{\mu_\circ \varepsilon_\circ}}\sqrt{\frac{2}{\varepsilon r + 1}} = \frac{\vartheta_\circ}{2fr}\sqrt{\frac{2}{\varepsilon r + 1}} \tag{2.6}$$

where $\vartheta_\circ$ is the free-space velocity of light.

2. Determine the effective dielectric constant of the microstrip antenna using (2.1).

3. Once W is found using (2.6), determine the extension of the length ΔL using (2.2).

4. The actual length of the patch can now be determined by solving (2.5) for L, or

$$L = \frac{1}{2fr\sqrt{\varepsilon_{reff}}\sqrt{\mu_\circ \varepsilon_\circ}} - 2\Delta L \tag{2.7}$$

Typical lengths of microstrip patches vary between

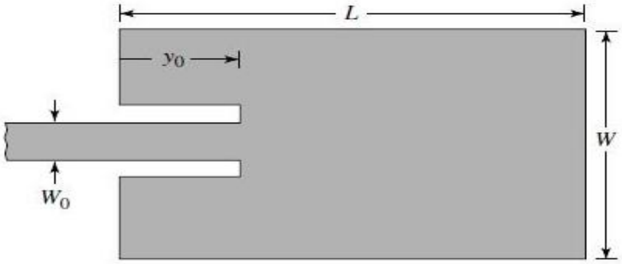
$$L \approx (0.47 - 0.49)\frac{\lambda_\circ}{\sqrt{\varepsilon_r}} = (0.47 - 0.49)\lambda_d$$

(2.7a)

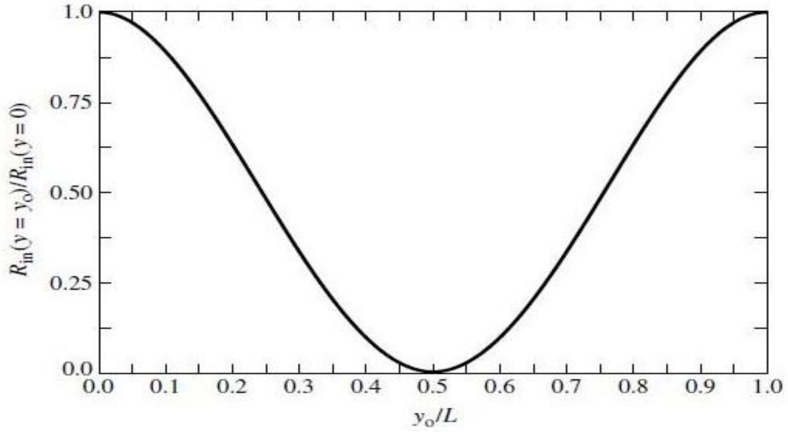
where λd is the wavelength in the dielectric. The smaller the dielectric constant of the substrate, the larger is the fringing; thus, the length of the microstrip patch is smaller. In contrast, the larger the dielectric constant, the more tightly the fields are held within the substrate; thus, the fringing is smaller and the length is longer and closer to half-wavelength in the dielectric.

2.1D. Matching Techniques:

This technique can be used effectively to match the



(a) Recessed microstrip-line feed



(b) Normalized input resistance

Figure 2.4Recessed microstrip-line feed and variation of normalized input resistance.

patch antenna using a microstrip-line feed whose characteristic impedance is given by

$$Z_c = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_{reff}}} \ln \left[\!\left[\dfrac{8h}{W_\circ} + \dfrac{W_\circ}{4h} \right]\!\right], & \dfrac{W_\circ}{h} \leq 1 \qquad (2.8a) \\ \dfrac{120\pi}{\sqrt{\varepsilon_{reff}} \left[\!\left[\dfrac{W_\circ}{h} + 1.393 + 0.667 \ln \left(\dfrac{W_\circ}{h} + 1.444 \right) \right]\!\right]}, & \dfrac{W_\circ}{h} > 1 \qquad (2.8b) \end{cases}$$

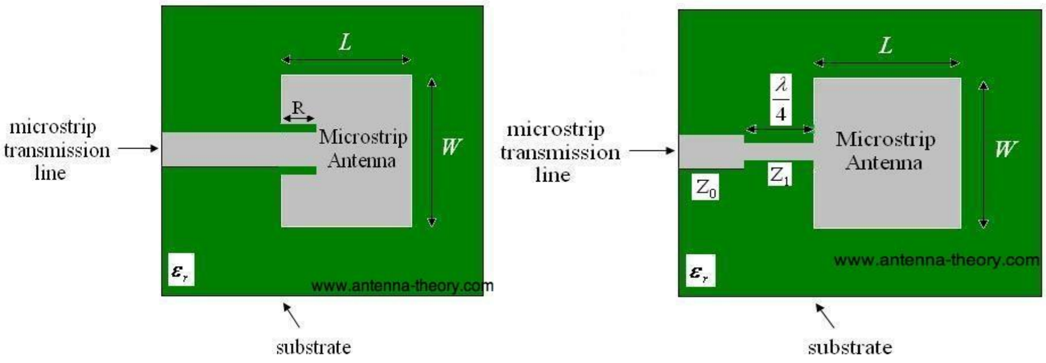
where $W_\circ$ is the width of the microstrip line, as shown in Figure 2.4. Using modal-expansion analysis, the input resistance for the inset feed is given approximately by

$$R_{in}(y = y_\circ) = \frac{1}{2(G_1 \mp G_{12})} \left[cos^2 \left(\frac{\pi}{L} y_\circ \right) + \frac{G_1^2 + B_1^2}{Y_c^2} sin^2 \left(\frac{\pi}{L} y_\circ \right) - \frac{B_1}{Y_c} \sin \left(\frac{2\pi}{L} y_\circ \right) \right] \qquad (2.9)$$

where $Yc = 1 / Z_c$. Since for most typical microstrips $G1 / Yc \ll 1$ and $B1 / Yc \ll 1$, (2-9) reduces to

$$R_{in}(y = y_\circ) = \frac{1}{2(G_1 \mp G_{12})} cos^2 \left(\frac{\pi}{L} y_\circ \right) = R_{in}(y = 0) cos^2 \left(\frac{\pi}{L} y_\circ \right) \qquad (2.9a)$$

A plot of the normalized value of (2-9a) is shown in Figure 2.4(b). The values obtained using (2-9) agree fairly well with experimental data. However, the inset feed introduces a physical notch, which in turn introduces a junction capacitance. The physical notch and its corresponding junction capacitance influence slightly the resonance frequency, which typically may vary by about 1%. It is apparent from (2-9a) and Figure 2.4(b) that the maximum value occurs at the edge of the slot (y0 = 0) where the voltage is maximum and the current is minimum; typical values are in the 150–300 ohms. The minimum value (zero) occurs at the center of the patch $(y0 \; = \; L \,/\, 2)$ where the voltage is zero and the current is maximum. As the inset feed point moves from the edge toward the center of the patch the resonant input impedance decreases monotonically and reaches zero at the center. When the value of the inset feed point approaches the center of the patch $(y0 \; = \; L \,/\, 2)$, the $cos2(\pi y0 \,/\, L)$ function varies very rapidly; therefore the input resistance also changes rapidly with the position of the feed point. To maintain very accurate values, a close tolerance must be preserved. Other matching techniques, aside from the recessed microstrip of Figure 2.4, are the coupled recessed microstrip and the $\lambda/4$ impedance transformer of Figure 2.5(a,b). The Rin in Figure 2.5(b) is the input resistance at the leading edge of the resonant patch; it must be real.(Balanis, 2016)



(a) Coupled

(b) λ/4 impedance transformer

Figure 2.5 Alternate feeding techniques of microstrip antenna for impedance matching.

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 Antenna Array Design:

Figure 3.1, fed by a microstrip transmission line. The patch antenna, microstrip transmission line and ground plane are made of high conductivity metal generally copper. The patch length , Width W, and sitting on top of a substrate of thickness h with permittivity εr . The frequency of operation of the patch antenna of figure 3.1 is determined by the length L, the center frequency will be approximately given by .

$$f_\circ = \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_r \varepsilon_\circ \mu_\circ}}$$

(3.1)

where;ε_r is the permittivity of substrate, $\varepsilon_\circ$ and $\mu_\circ$ are the permittivity and permeability of free space,L is the effective length of the patch,$c = 3 \times 10^8\, {}^{m}/_{s}$ The dimensions of the patch and substrate are calculated by.

Width of the patch : W

$$W = \frac{c}{2f_\circ\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

(3.2)

Effective dielectric constant:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}}$$

(3.3)

8h: thickness of dielectric substrate Fringing lengthΔL:

$$\Delta L = 0.412h \frac{\left(\varepsilon_{effr} + 0.3\right)}{\left(\varepsilon_{reff} - 0.258\right)} \frac{\left(\frac{w}{h} + 0.264\right)}{\left(\frac{w}{h} - 0.8\right)}$$

(3.4)

Length of patch L_p:

$$L_p = L - 2\Delta L$$

(3.5)

Length of substrate L_s:

$$L_s = 6h + L_p$$

(3.6)

Width of substrate W_s:

$$W_s = 6h + W$$

(3.7)

The Edge-Fed 4x1 microstrip patch array antenna designed at 28 GHz frequency with RT5880 as substrate with dielectric constant $\varepsilon r = 2.2$, loss tangent $tan(\delta) = 0.0009$, substrate thickness $h = 0.508mm$ and copper thickness $t = 0.035mm$ was used.

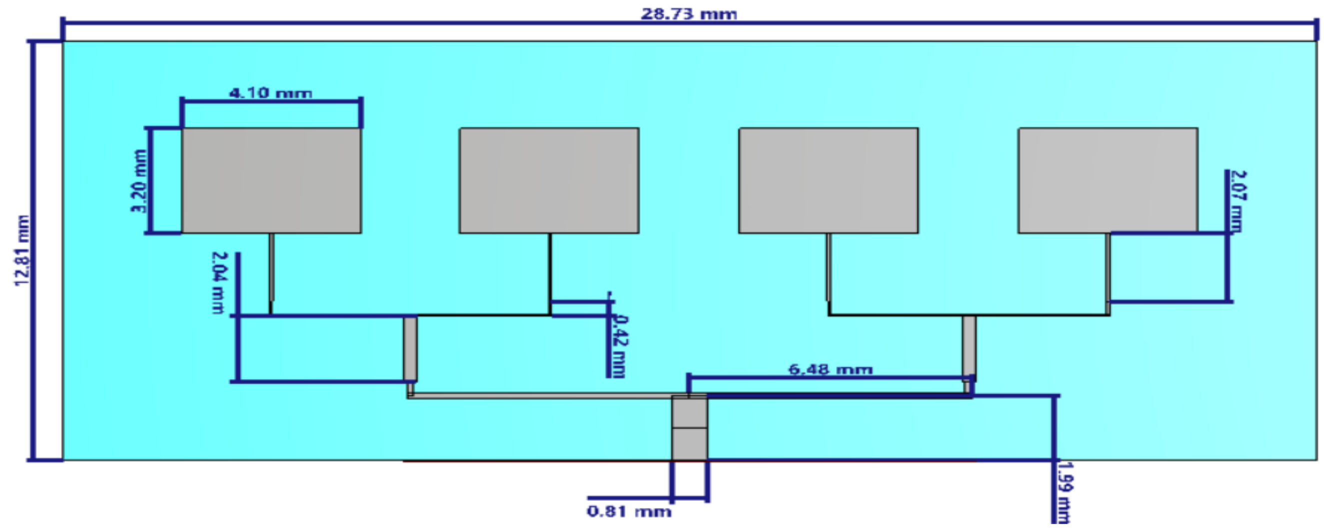


Figure 3.1. Microstrip antenna array as 4x1 elements.

Figure 3.2,depicts the return loss characteristics of the proposed 1x4 array antenna. From the figure, it is observed that the array antenna has a wide response in the range of 28GHz for V band applications. From this fig 3.2 It is inferred that the impedance bandwidth of the array elements is >26 GHz. The ratio of the difference between two frequencies and the resonant frequency obtains the impedance bandwidth in GHz. The proposed antenna has the impedance bandwidth of 13.4% GHz

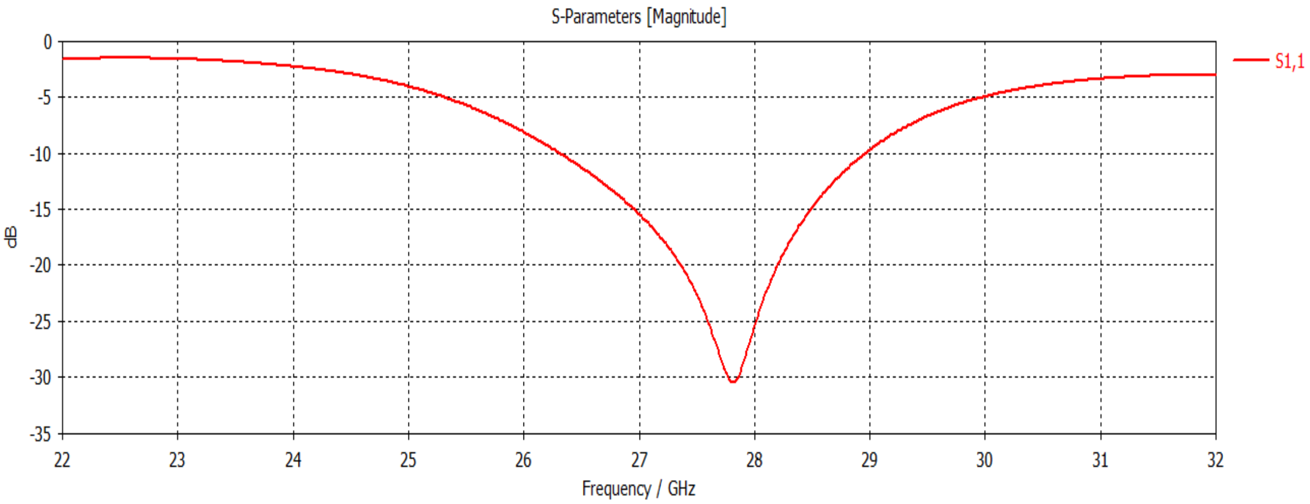


Figure 3.2. S11-parameters of 4x1 printed antenna array.

Figure3.3 , gain can be calculated by using the parameters such as directivity, loss of the transition and the loss of the radiating patch with the help of reference antenna. The gain of the antenna is propotional to the directivity of the antenna. From the Fig 3.3 it is observed that the proposed array antenna has the increased gain which improves the performance of the antenna.

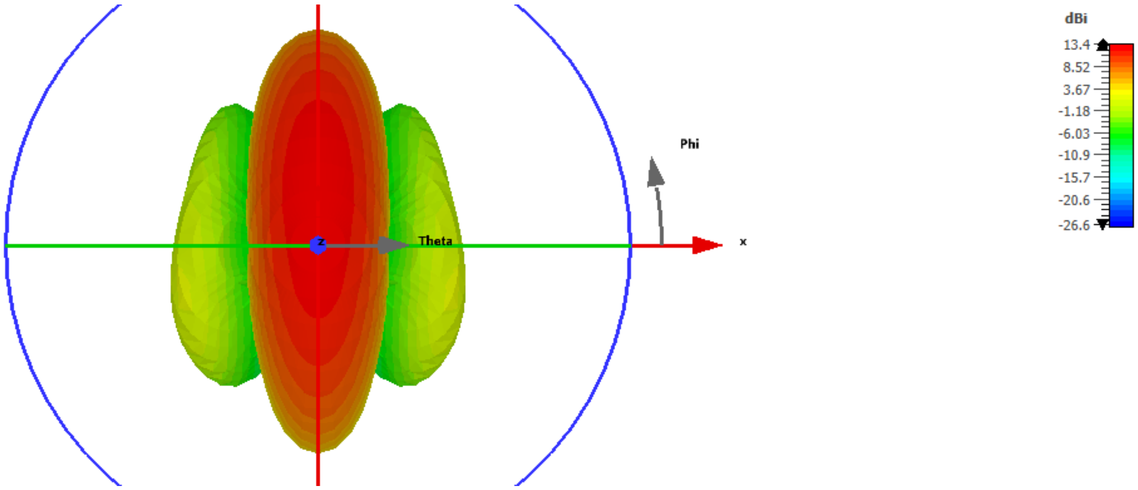


Figure 3.3. Gain radiation plot of 4x1 printed antenna array.

Table3.1, all the antenna parameters have been optimized in a way so that the studied antenna can achieve better performance in terms of gain and bandwidth , Table 3.1 shows that the bandwidth is 9.6%, In general, the designed microstrip patch antenna performs exceedingly well when compared to previous works reported.

Table 3.1: Detailed results of proposed antenna .

Resonant Frequency	S11 (dB)	BW (%)	Gain (dB)
28	-30	9.6	13.4

CHAPTER FOUR

CONCLUSION AND FUTURE WORK

4.1Conclusion:

the microstrip patch antenna array presents a promising solution for 5G applications due to its compact size, low profile, and high gain. Through proper design and optimization, it offers enhanced performance in terms of bandwidth, efficiency, and beam steering capabilities, making it well-suited for the demands of 5G communication systems. In the different operating frequency bands, the maximum gain of the antenna is more than 13 dB, and it has good directivity as radiation shapes as main and side lobes. The designed frequency reconfigurable array antenna has a certain guiding significance for the reconfigurable design of the antenna array and has a good application prospect in the antenna array system. As 5G networks continue to evolve, the microstrip patch antenna array stands as a reliable and efficient component for meeting the growing demands of high-speed data transmission, massive connectivity, and diverse applications.

4.2 Future Work:

In the future, microstrip patch antenna arrays are likely to see advancements in several areas:

1.Miniaturization: Continued efforts will focus on making the antenna arrays smaller and more compact while maintaining or enhancing their performance.

2.Multiband and Wideband Operation: Antenna arrays that can operate across multiple frequency bands or over a wide bandwidth will become increasingly important for diverse communication applications.

3.Beam Steering and Beamforming: Advancements in beamforming techniques will enable more precise control over the directionality of the antenna arrays, allowing for adaptive beam steering and improved signal reception.

4. Integration with other Technologies: Integration with other emerging technologies such as 5G, Internet of Things (IoT), and millimeter-wave communication systems will drive the development of more versatile and efficient antenna arrays.

5.Enhanced Efficiency and Gain: Techniques for improving the efficiency and gain of microstrip patch antenna arrays will be explored, enabling better performance in terms of signal transmission and reception.

Overall, future work on microstrip patch antenna arrays will likely focus on improving performance, versatility, and integration with emerging technologies to meet the evolving demands of wireless communication systems.

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