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العدد التاسع والعشرون، 2023

Performance Optimization and Analysis of Microstrip Patch Antenna Array for 5G and Beyond

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تاريخ الاستلام: 2023-06-09 تاريخ القبول: 2023-06-27 تاريخ النشر: 2023-09-07

Abstract: Modern smartphones demand a very high bandwidth, making the 5G communication technology a revolution in the wireless communication business. Researchers are motivated to advance communication technology, whether in the software or hardware sectors, by this quick transformation. Additionally, antenna design is regarded as a fundamental topic that requires constant advancement to support 5G wireless communication systems.

This paper's major objective is to create a planner microstrip antenna array that will support 5G communication systems by including all crucial aspects of current wireless communication systems and making use of huge MIMO antenna. The suggested antenna is built to function at 28GHz, a high frequency (mm-waves). The suggested design's large bandwidth (>1 GHz) and high realized gain (>8 dB) satisfy the key aspects of 5G. A two antenna array design with horizontal series-feed components to a planar configuration design is offered as an antenna array to improve the directivity and realized gain of the antenna design. The 11x112 element array (11V12H) design of the proposed antenna must achieve a high gain and high bandwidth at the operating band. A phase shifter (transmission line) is included into the eleven series-feed element configuration to enable beam steering. With this upgrade, the option to tilt the primary radiation pattern in a certain direction was added.

The outcomes demonstrate It is discovered that the suggested antennas accomplish strong pattern diversity, high gain, great directivity, high radiation efficiency across the working band, and very tolerable bandwidth in the aforementioned range, making them extremely suited for 28 GHz band use. The suggested antenna has an 8.71 dB gain and an 8.83 dB directivity. By utilizing a large MIMO antenna, these capabilities are particularly beneficial for wireless communication equipment used in 5G and beyond. Using Ansoft HFSS, the suggested antennas' simulation was performed.

Keywords: (Fifth generation (5G), Voltage Standing Wave Ratio (VSWR), Return Loss (S))

Introduction

The launch of 5G devices that use mm-wave frequencies has posed tough problems for the communications sector, especially for mobile devices. Compared to low frequency bands, mm-wave bands have a higher path loss. Using antenna arrays with higher gains to make up for the significant path loss is one possibility. High-gain antennas provide narrow beamwidth because the gain is inversely related to radiation beam width. Beam scanning is therefore necessary to increase spatial coverage. Although phased arrays may be used to perform beam scanning, they are often narrow-band, expensive, hard to install since phase shifters are used, and take up more space in contemporary wireless terminals. Therefore, a substitute for phased arrays at mm-wave frequencies is provided by multi-port antennas MIMO, which provide numerous directional beams [1]. Figures (1a) and (1b) compare a standard phased array, which requires phase shifters to direct the beam, and a switchable antenna array, which requires a switch to excite a particular antenna to cover a certain section of the space.

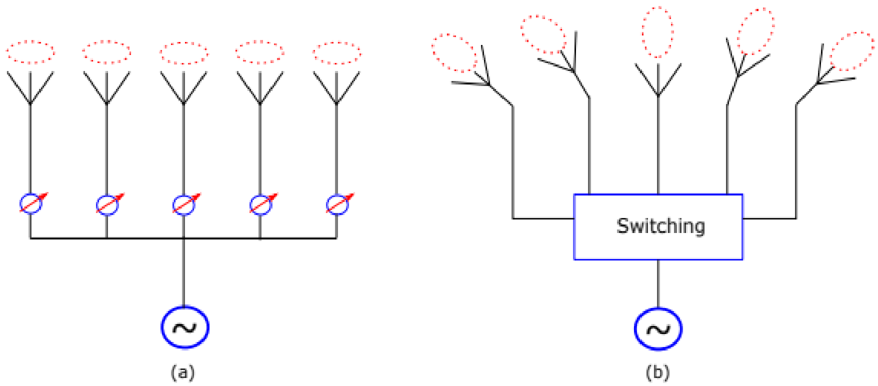

Fig. 1: Antenna array. (a) Phased and (b) switchable [19].

The antenna array's array element consists of several subarrays. A 2D array is made up of several horizontal rows and vertical columns of subarrays. The fundamental concepts and technologies of massive MIMO in the 5G NR system are represented by this huge MIMO antenna. A huge number of antennas are used, which produces precise, user-specific beams and boosts the received signal power. It also lessens the degree of interference with other users. Therefore, a large number of antennas can enhance the overall signal quality. Massive MIMO systems can come in a variety of shapes and sizes depending on where the antenna pieces are positioned. It is possible to assess the features of the huge MIMO radio gear by dissecting it into its various parts. One of the key elements that affects how well a large MIMO system performs is angular coverage, particularly when the system is installed in a building like a stadium or skyscraper and the connected users are dispersed in both horizontal and vertical directions. Antennas A base station may focus its broadcast power into a series of tiny beams by using a lot of antennas. The form and direction of the broadcast signals can be controlled by the base station if it has the capacity to dynamically change the phase and amplitude of (groups of) antenna components. The advantages listed below can thus be anticipated in cellular systems.

1. Enhancement and structuring of the coverage.
2. Enhanced throughput for a single user.
3. Cell throughput increase with numerous spatial divisions.

Dimensions of Massive MIMO Because the antenna array of a base station comprises of subarrays, applying separate digital beamforming (BF) to every antenna element is inefficient in terms of development costs and cell angular coverage. The azimuth and elevation angles would be constrained to a specific range depending on the geometric distribution of the users even if one were to operate a 2D AAS utilizing numerous antenna components. Additionally, since base station antennas are frequently situated in high places like rooftops or masts, their elevation angle does not need to be in the whole range of -90° to 90° in the vertical direction, which would result in excessive transmission power loss. Thus, a subarray is formed by connecting just a single RF transmit/receive chain, which includes a power amplifier and a low noise amplifier, to a small number of neighboring antenna components that are normally oriented in a vertical orientation. Figure (2) shows a 32T32R massive MIMO radio with a subarray made up of three antenna components (N_{sub} = 3).

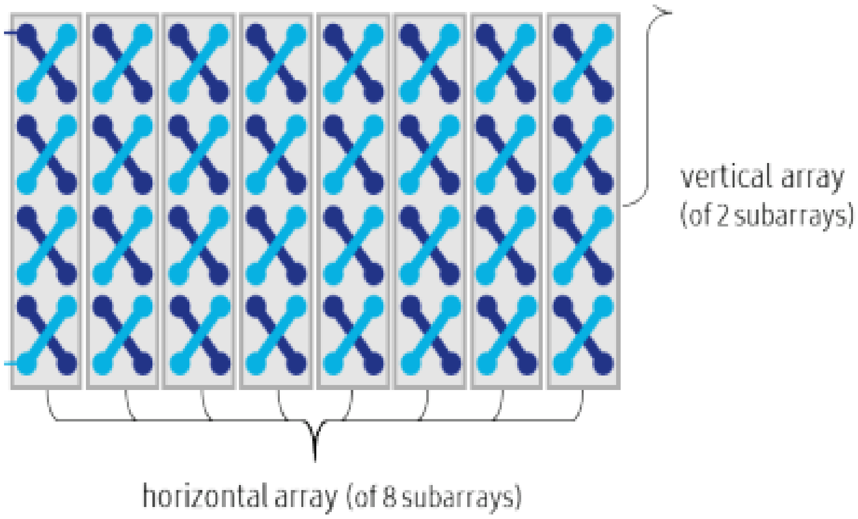

Fig. 2: An example of massive MIMO radio configuration.

A phase shifter or other extra RF device is needed to change a subarray's steering angle since only one digital BF weight is applied inside the subarray [2].
This study introduces the design and analysis of a large MIMO antenna that uses a microstrip antenna array. It is intended to operate at 28 GHz, which is the band used for 5G applications. It succeeds in one band. The suggested antenna is a base station antenna with a good gain at a reasonable price and weight. The prototype antenna array's characteristics, including return loss (RL), bandwidth, VSWR, gain, directivity, and radiation pattern, have been examined.

1. Microstrip Antenna

Microstrip antennas have emerged as one of the most cutting-edge areas of antenna theory and design in recent years, and they are increasingly being used in a variety of contemporary microwave systems [3]. This study gives a general review of the fundamental properties of array and MIMO-style microstrip antennas. Also considered is a new antenna arrangement for better performance.

2. Microstrip Antenna Analysis

The transmission line model, cavity model, and full wave model [4] (which predominantly uses integral equations/Moment Method) are the three models that are most frequently used for the study of Microstrip patch antennas. The transmission line model is the most straightforward and provides the best physical understanding, but it is also the least accurate. Although more complicated in nature, the cavity model is more precise and provides useful physical understanding. Full wave models can handle single elements, finite and infinite arrays, stacked components, arbitrary shaped elements, and coupling. They are also incredibly precise and adaptable. These are far more complicated and provide less information than the two models listed above. This model depicts the microstrip antenna as two slots that are separated by a transmission line that is L in length and W in width. In essence, the microstrip is a non-homogeneous line made of two dielectric materials, usually the substrate and air. Figure (3), which has a thickness of t, depicts the distribution of electric field lines in a transmission line mode.

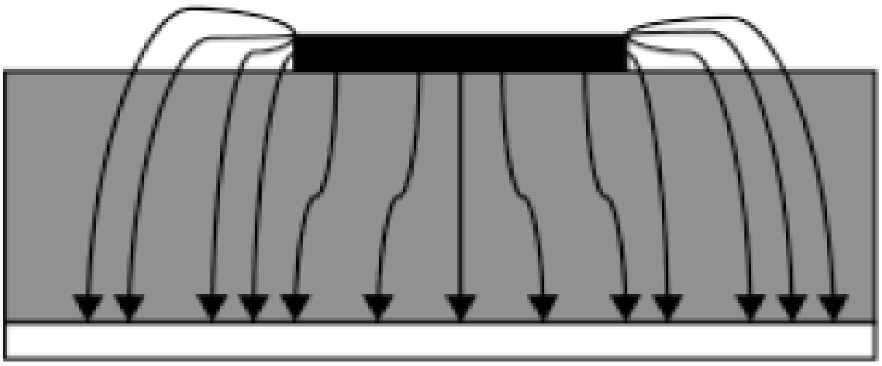

Fig.3: Electric field lines in a transmission line.

Since TEM refers to the direct transfer of electric field lines to the dielectric, it results in the fact that transmission lines cannot support transfer-electric-magnetic TEM. This cannot be allowed, as can be shown in Figure 4, as part of the electric field lines exit into the atmosphere before reaching the dielectric substrate[4, 5].

Relative permittivity will be substituted by _reff, which is somewhat less than _r and is supplied in relation to this issue of transferring field lines into air before it penetrates the dielectric. as [5].

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{1+\frac{12h}{W}}} \quad W/h>1 \qquad (1)$$

Where ε_r h, w, are the substrate dielectric constant, the dielectric substrate height and the patch width respectively. The affective dielectric constant is also a function of resonant frequency fr equation (2).

$$f_r = \frac{v_0}{2\sqrt{\varepsilon_{eff}}(L+2\Delta L_{eff})} \qquad (2)$$

Since there is just one dielectric substrate under and above the transmission line and working at high frequencies makes the microstrip line more homogenous, the effective dielectric constant is also closer to the real dielectric constant.

According to the plan, the patch's length will be increased on both sides as a result of the movement of electric field lines through the atmosphere, as shown in Figure (4). Figure (4) shows that with vertical polarization (Ev), the electric field lines are oriented in opposing directions on both of the width's edges. Actually, because of the out-of-phase situation, they annihilate one another. The horizontal polarization, on the other hand, is in phase. By combining the resultant fields, the maximum radiated field is produced. It makes sense to assume that the Microstrip Patch Antenna's two slots are what generate the antenna radiation.

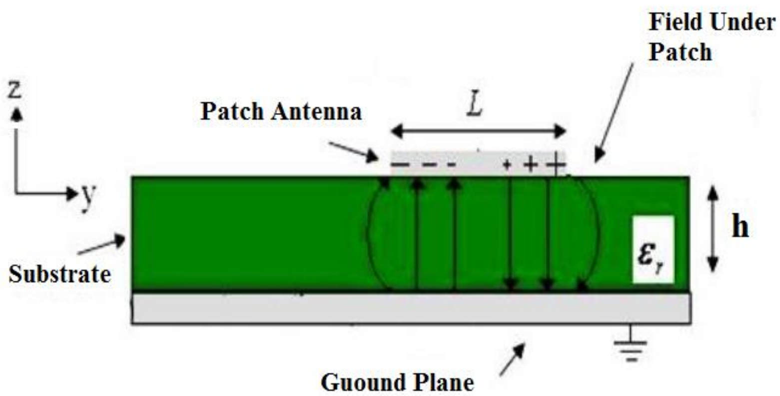

Fig. 4: The Electric Field lines on both edges of microstrip antenna.

A relatively common relation for the normalized extension of the length is [3, 5], which is used to calculate the extension of the length ΔL. $$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (3)$$

The characteristic impedance of the microstrip line can be written as:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon reff}(1.393+\frac{W}{h}+\frac{2}{3}\ln(\frac{W}{h}+1.444))} \quad (4)$$

A relatively common relation for the normalized extension of the length is [3, 5], which is used to calculate the extension of the length L:

Antenna Width

The following equation is used to compute the width w [6]:

$$W = \frac{c}{2f_c\sqrt{\frac{\varepsilon r+1}{2}}} \quad (5)$$

Where, c is the speed of light, *f* and ε_r are respectably the resonance frequency and the dielectric constant of the substrate.

Antenna Length

The effective length L_{eff} can be calculated by the following equation [6]:

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}} \quad (6)$$

Then the actual length of the patch is given by the following equation [6]:

$$L = (L_{eff} - 2\Delta L) \quad (7)$$

Ground Planes

The transmission line concept is essentially limited to an unlimited ground plane. However, it has been proven that a finite ground plane may also be employed, if the ground plane is six times greater than the height of the dielectric substrate, plus the needed length or breadth. The ground plane width and length may now be estimated correspondingly as [6]:

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

$$L_g = 6.h + L \quad (9)$$

3. Microstrip series-feed linear antenna array for 5G application

A 12-element series-feed linear array of rectangular microstrip antenna is presented in this paper. The suggested design comprises of 12 identical rectangular microstrip patches linked with each other by meandering series lines. About half of a wavelength's worth of feed lines link the devices. This permits in-phase fields in the neighboring patches. The array is fed at the middle patch, resulting in a broadside radiation pattern with no beam tilt and symmetrical amplitude distribution. Rectangular microstrip patch antenna comprises of a rectangular shape radiating patch on one side of dielectric substrate which positioned on a ground plane. For acquiring the high performance of patch antenna we must attentive about the height, dielectric constant of material and operating frequency.

4. Antenna Design

The design of the suggested array starts with a design of a conventional antenna utilized to function in 5G frequency range (centered at 28 GHz) in the section 3. The geometry uses linear array of rectangular microstrip antenna, as illustrated in Figure (5). The microstrip series-feed line is used to improve the impedance matching between the element and the feed line. The dimensions of the antenna are: W = 18 mm, L = 19.3 mm. The feed is obtained through a microstrip line with 2.5x 0.4 mm. The two parts of antenna are joined together with little distance between them as indicated Figure (5), as it helps the integration of the array with other RF circuits. The substrate employed was the Duroid 5880 with εr= 2.2, and h=1.6 mm.

Fig.5: Proposed A 12-element series-feed linear array of rectangular microstrip antenna.

After simulation and optimization using HFFS Software, the final dimensions are shown in the Figure (6).

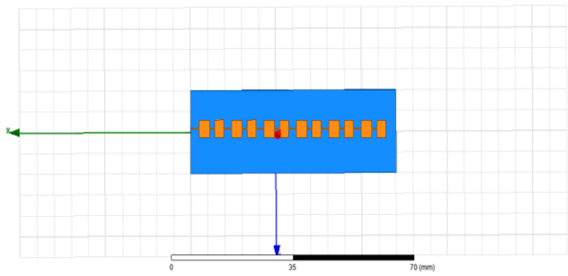

Fig.6. View of A 12-element series-feed linear array of rectangular microstrip antenna, dimensions (mm).

The published structure is carried out in HFSS. The appropriate simulations are carried out to acquire the scattering parameters. The collected findings matched the published results which completes the antenna validation.

4.1 Simulated Results

The simulated reflection coefficient of the series-feed linear array of rectangular microstrip antenna is illustrated in Figure (7). It is clear that the described antenna can functioning band (under -10 dB) at centered 28GHz (-12 dB),with bandwidth which runs from 26.4GHz to 28.7GHz (FBW 8.2%). So, it is pretty evident that this operating band fulfill the design criteria of 5G standard operating frequency.

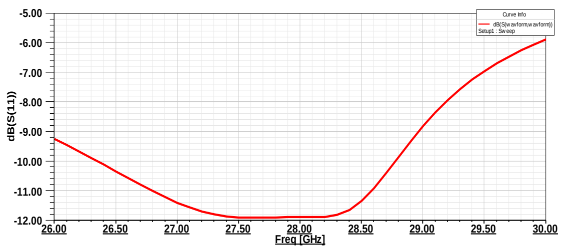

Fig.7: Simulation results of the series-feed linear array of rectangular microstrip antenna.

Figure (8), illustrate the VSWR for 5G microstrip antenna array with good values, we had 1.6 at 28 GHz, this signifies good received signals.

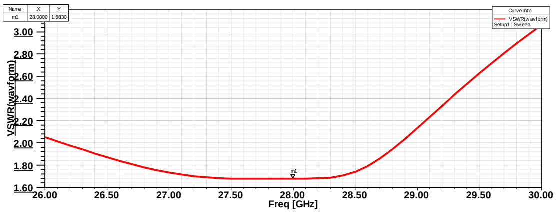

Fig. 8: VSWR of the series-feed linear array of rectangular microstrip antenna.

5. Phased microstrip Linear Antenna Array for 5G Application

One key objective of creating phased-array antennas is to perform beam guiding electronically and therefore to remove the mechanical movement of an antenna system. Electronic beam steering in an array antenna can be done via time delay scanning, frequency scanning or phase scanning methods. However, ease of implementation, inexpensive digital control circuits, rapid reaction time and great sensitivity make the phase scanning approach the most preferred. For optimal operation, a wise alternative for a phase shifter is a switched line or ferrite phase shifter with analog or digital control. A proper decision for the positioning of phase shifters along the feed line is also a very essential element. The orientation may be in series or in parallel. Although the series phases have the advantage of sharing equal power, the downside is the phase compensation circuit since the fundamental inter-element phase shift must be multiplied by the number of elements and the attenuations of the phases build up along the feed line. On the contrary, with parallel combination, although each phase shifter does not share the same power, the key advantage is all phases are independent of each other and therefore modeling of the control circuit becomes easier.

A 11-element linear array of rectangular microstrip antenna identical individual microstrip patch antennas functioning at 28 GHz have been developed and produced as a part of the test platform. These 11 antennas can be implemented as an array.

6.1 Antenna Design

The design of the suggested array starts with a design of a conventional antenna utilized to function in 5G frequency range (centered at 28 GHz). The geometry uses linear array of rectangular microstrip antenna, as illustrated in Figure (9). The microstrip feed line is used to enhance the impedance matching between the element and the feed line. The dimensions of the antenna are: W = 55 mm, L = 8 mm. The distance between the center of two elements has been reached to > 0.5 λ., as it enables the integration of the array with other RF circuits. The substrate employed was the Rogers RT/duroid5880™, with 〖εr〗_= 2.2, and h = 1.6 mm.

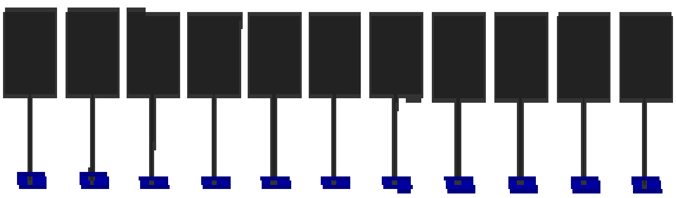

Fig. 9: Proposed A 11-element linear array of rectangular microstrip antenna.

After modeling and optimization using HFFS Software, the final dimensions are presented in the Figure (10).

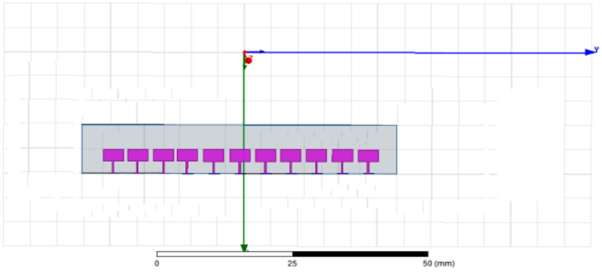

Fig. 10: View of A 11-element linear array of rectangular microstrip antenna, dimensions.

The published structure is carried out in HFSS. The appropriate simulations are carried out to acquire the scattering parameters. The collected findings matched the published results which completes the antenna validation.

6.2 Simulated Results

The simulated reflection coefficient of the series-feed linear array of rectangular microstrip antenna is illustrated in Figure (11). It is clear that the stated antenna can operate band (under -10 dB) at centered 28 GHz (-11.9 dB), with bandwidth which ranges from 26.4 GHz to 28.7 GHz (FBW 8.2%). So, it is pretty evident that this operating band fulfill the design criteria of 5G standard operating frequency.

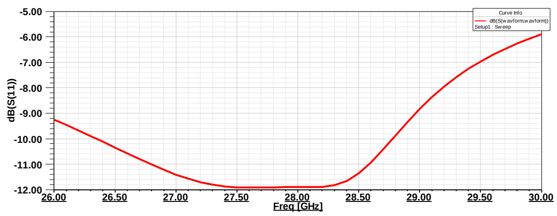

Fig. 11 .Simulation results of rectangular microstrip antenna array.

Figure (12), demonstrate the VSWR for 5G microstrip antenna array with good values, we had 1.6 at 28 GHz, this signifies good received signals.

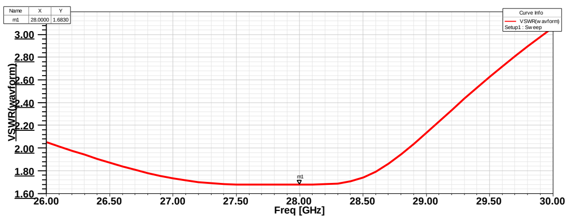

Fig. 12 .VSWR of rectangular microstrip antenna array.

The goal of this study is to develop a microstrip antenna with high directional gain for band 28 GHz applications. Initially we configured our antenna as a single element microstrip patch antenna and after assessing the outcomes of antenna characteristics, operating frequency, radiation patterns, reflected loss, efficiency and antenna gain, we turned it to a series-feed linear array of rectangular microstrip antenna. To enhance more directivity, gain, efficiency, and have better radiation patterns, we designed and studied horizontal arrays of rectangular microstrip antennas and series-feed linear arrays in the following section.

6. Phased Microstrip Antenna Array (1V11H) for 5G Application

Using HFSS, a rectangular microstrip patch antenna array is created by arranging identical horizontal and series-feed components in a planar arrangement. 11x11 (1V11H) shaped patches are arranged into an array to make up the specified element array. the same impedance matching feeding method using a microstrip line. With this method, each antenna element receives an identical amount of power.

7.1 Design Principles

According to Figure (13), the suggested antenna is made up of 11x112 components (1V11H). All of the planned arrays' feeding networks are the same size as a single patch antenna.

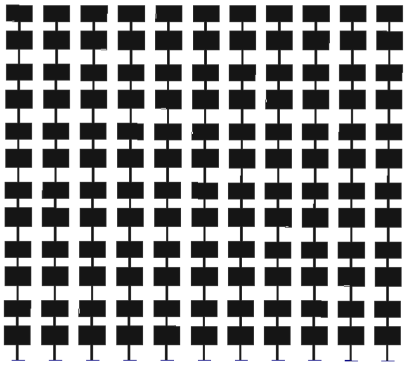

Fig. 13. Proposed geometry of microstrip antenna array.

The antenna is made of a Duroid 5880 substrate with an εr value of 2.2 and has dimensions of 166 mm in length and 84 mm in breadth. It may be readily integrated onto the same substrate. Every two vertical components now have a gap between them of greater than 0.5. The patches are designed to improve gain and return loss directivity. The suggested is quite inexpensively and simply fabricatable. The array's shape is shown in Figure 13 using all available dimensions.

After simulation and optimization using HFFS Software, the final dimensions are shown in the Figure (14).

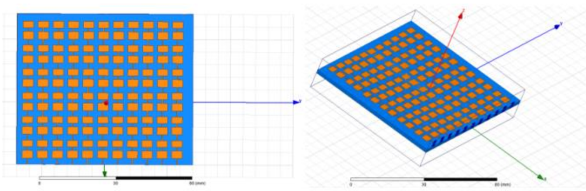

Fig. 14 .View of proposed microstrip antenna array, dimensions (mm).

7.2 Simulated Results of Proposed Antenna

The planned microstrip patch antenna array has already been designed. Using electromagnetic full wave simulation (HFSS), this has been verified.

a- Antenna Return Loss

Figure (15) displays the 11x12 microstrip patch antenna array's simulated reflection coefficient. It is clear that the stated antenna is capable of using the 5G frequency. The operational band's bandwidth ranges from 26.4 GHz to 30.2 GHz (FBW13.5%), with a central frequency of 28 GHz (under -10 dB) and a slope of -14.36 dB. Therefore, it is abundantly obvious that this operating band complies with the 5G standard operating frequency design criteria.

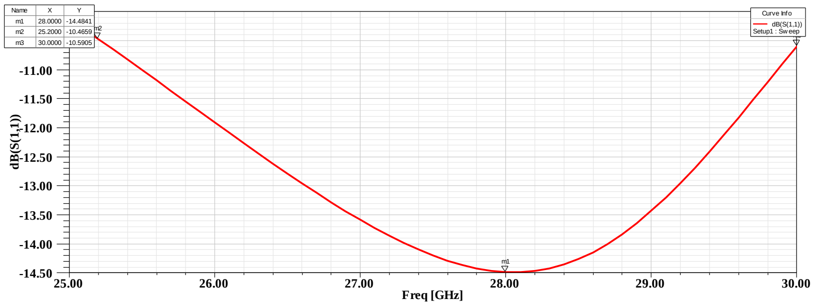

Fig. 15 .The return loss of the proposed microstrip antenna array.

b- Voltage Standing Wave Ratio (VSWR)

Figure (16) displays the VSWR for a 5G application with favorable results; we got a range of 1.4 in the 28 GHz band, which indicates excellent received signals (no reflection).

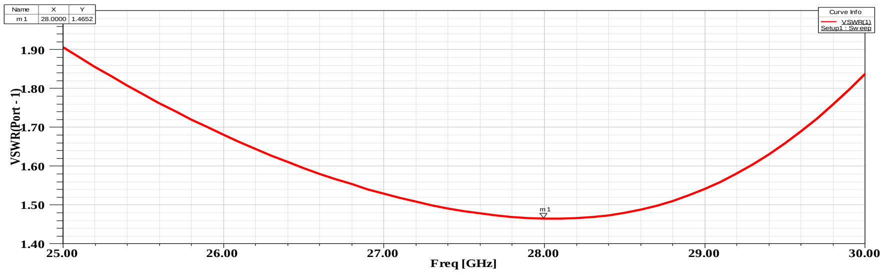

Fig. 16 .VSWR of the proposed microstrip antenna array.

c- Radiation Pattern

Figure (17) depicts the radiation patterns for the proposed microstrip patch antenna array for 5G. Since the antennas are patch type, the radiation patterns in the phi=0 deg (x-y plane) and phi=90 deg (y-z plane) planes are directional as would be expected. The antenna's directional pattern is present in every component.

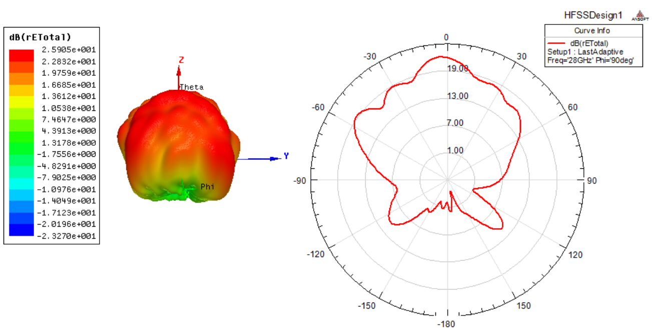

Fig. 17 .2D and 3D radiation pattern of the proposed microstrip antenna array.

d- Gain and Directivity

Peak measured gain for the proposed design is 8.71 dB, whereas peak simulated directivity is 8.83 dB.

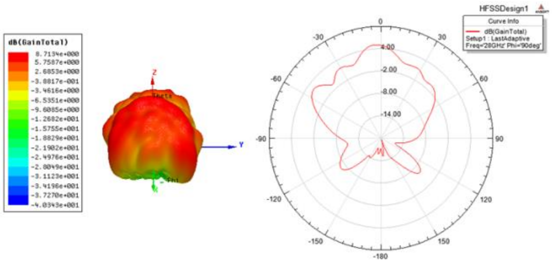

Fig. 18 .2D and 3D gain of the proposed microstrip antenna array.

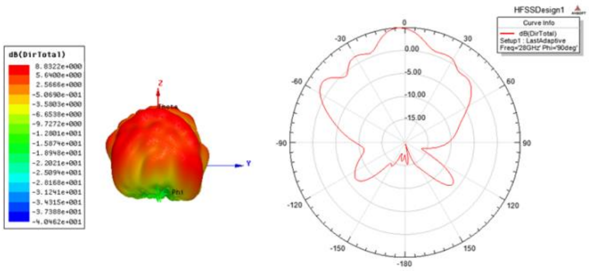

Fig. 19 .2D and 3D directivity of the proposed microstrip antenna array.

The maximal antenna efficiency is also around 97%. Figures (18) and (19) below show 2D and 3D far field plots of the planned antenna's radiating gain and directivity. The antenna's gain and directivity are also good.

e- Current Distribution on the proposed antenna.

The red arrows in Figure (20), which depicts the current distribution pattern at 28 GHz, indicate the strongest current spread in the antenna patch.

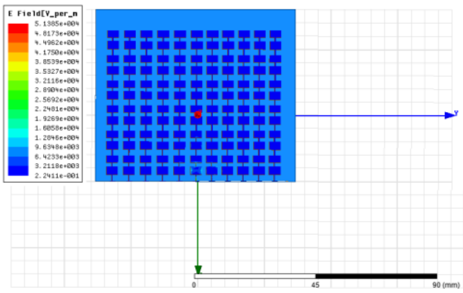

Fig. 20 .Current distribution on the microstrip antenna array.

Conclusion

In this study, we present the findings for the linear, horizontal, and series-fed planned rectangular microstrip patch antenna array constructed using HFSS for the 28 GHz band. The influence on the gain, directivity, and scattering pattern is seen.

The constructed of element antenna arrays in series-feed elements array antennas consists of 12 shaped patches with proportions equivalent to those of a single shaped antenna. With a bandwidth of 26.4 GHz to 28.7 GHz (FBW 8.2%), the simulated return loss parameter is better than -10 dB (-12 dB), and the minimum value of VSWR is around 1.6 at 28 GHz. Finally, in order to further optimize the parameters, planner microstrip array antennas are introduced. In order to create the rectangular microstrip patch antenna array, identical horizontal and series-feed components were arranged in a planar manner. The 11x12 ((11V12H) shaped patches that make up the intended planner array are arranged into an array. the same impedance matching feeding method using a microstrip line. With this method, each antenna element receives an identical amount of power. When designing the array, a space between elements greater than 0.5 is employed. The bandwidth of the return loss, which ranges from -14.36 dB to 30.2 GHz (FBW13.5%), is 26.4 GHz to 26.4 GHz. The better VSWR is 1.56 dB. The antenna's field gain is 8.71 dB, and its directivity is 8.83 dB. The suggested antennas can be made quickly and cheaply and have directed emission patterns, which are valuable. Utilizing a substrate material with a low dielectric constant, the antennas are small and thin. The suggested antennas are simple and inexpensively fabricatable. For usage in huge MIMO antenna and 5G wireless communication equipment, these properties are particularly beneficial. All simulations in this study were done using the electromagnetic program Ansoft HFSS. In addition, the antenna is small and can cover the whole 5G frequency spectrum.

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