Design and Analysis of 28GHz Rectangular Microstrip Patch Array Antenna

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Abstract: The higher frequency spectrum prevalence of the next generation of mobile communication, as well as other new service applications, will likely be dependent upon new advanced antenna technologies. In this regard, the narrow beam widths generally associated with antennas at higher frequencies has led to the study of using advanced multiple-input multiple-output (MIMO) architecture as well as adaptive beam-forming. These antenna technologies may be among the key factors for overcoming some of the challenging propagation characteristics of mm-waves and could increase the spectrum efficiency, provide higher data rates, and adequate reasonable coverage for mobile broadband services. With the potential for higher frequencies as well as mm waves deployment, most 5G frequency bands are predicted to be in the range of 20-50GHz. More specifically, the frequency band of 5G is predicted to be extended from 28GHz to 38GHz. In this paper, 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.

Keywords: Antenna Design, Fifth generation, FR-4, Antenna gain, Microstrip patch antenna, 4x1 linear array antenna

I Introduction

As a universal part of daily work and personal life, the development of the mobile phone device entails the opportunity to examine how technology drivers are pushing for the integration of real life with mobile technology in future. In other words, mobile communication has become more popular in last few years due to fast revolution in mobile technology. Over the last few years, wireless telecommunications market has recognized as one of the most dynamic and fastest growing segments of the global telecommunications industry. In this regard, the world has witnessed four generations of mobile communication technology, with each new generation extending the capabilities and enhancing the end-user experience compared to the previous generation. From this point of view, global system of mobile communication has many developments starting from 1G passing by several modifications till the emerging of 4G. These versions introduce many services including voice, text, and multi-media. 3G and long term evolution (LTE) have the characteristics of transmitting and receiving data with high rate. However, there is an increasing demand on that rate to become higher and higher to reply the future requirements. So, we are going forward towards next generation, 5G, which will integrate all different technologies in such a way that the global service will be enhanced. These services include higher mobile data volume per area, huge number of connected devices, longer battery life for low power devices, five times reduce end to end latency, and user data rate which is higher 10 t o 100 times than the existing one. Generally, the 5G cellular networks are expected to meet high-end requirements. These networks would provide novel constructions and techniques beyond state-of-the-art architectures and technologies. In other words, the networks of the next generation are broadly characterized by three unique features:

Ubiquitous connectivity: It is predicted that many types of devices will connect ubiquitously and provide an uninterrupted user experience, which means that the user-centric view will be realized by ubiquitous connectivity [1-3].

Zero latency: The 5G networks will support life-critical systems, real-time applications, and services with zero delay tolerance. Hence, it is envisioned that 5G networks will realize zero latency, i.e., extremely low latency of the order of 1 millisecond. In fact, the service-provider-centric view will be realized by the zero latency.

High-speed data transfer: The zero latency property could be achieved using a high-speed connection, in the order of Gb/s to users and machines, for fast data transmission and reception.

As fifth generation is developed and implemented, it is believed that the main differences compared to 4G will be the use of much greater spectrum allocations at untapped mm-wave frequency bands, highly directional beam forming antennas at both the mobile device and base station, longer battery life, lower outage probability, much higher bit rates in larger portions of the coverage area, lower infrastructure costs, and higher aggregate capacity for many simultaneous users in both licensed and unlicensed spectrum. To reply these required characteristics, the cellular systems will be shifted to higher frequencies where it is easier to achieve wider bandwidths which are needed for these aspects. Therefore, the backbone networks of the predicted generation will move from wired to mm-wave wireless connections, allowing rapid prevalence and mesh-like connectivity with cooperation between base stations. As Fig.(1) depicts, the cm/mm wave bands could provide bandwidths several times broader than 3G and 4G frequency bands. Therefore, these wave bands can support higher data rates that are required for many applications in the future. However, moving to the indicated wave bands would bring new challenges in the designs of antennas for mobile phone devices. Additionally, since the path loss increases as the operating frequency increases, the smaller antennas arranged as an array are preferred for millimeter applications in order to get the required gain overcoming the effects of attenuation [4, 5].

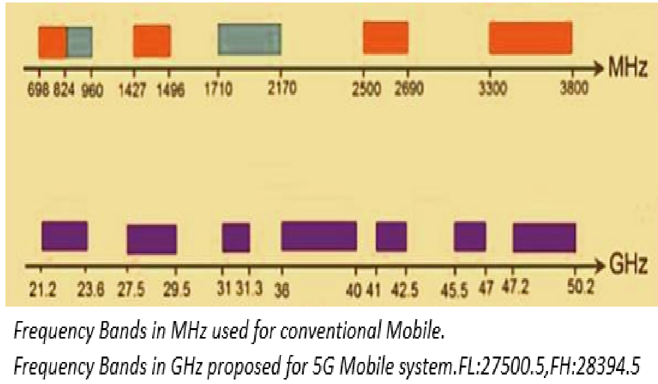

Fig.(1) 3G & LTE bands and proposals spectrum for 5G (20-50GHz)

Due to its high performance, a horn antenna is generally used at mm-wave frequency band. However, it is heavy, bulky and expensive as well as it requires comparatively high power and have additional losses. Therefore, it is needed to search another type of antennas that emits and receives around 28 GHz for wireless applications. In telecommunications, a microstrip antenna usually means an antenna fabricated using microstrip techniques on a printed circuit board (PCB). It is mostly used at microwave frequencies. This type of antennas has become very popular in recent decades owing to its thin planar profile which can be incorporated into the surfaces of consumer products, aircraft and missiles, its ease of fabrication using printed circuit techniques, its simplicity of integrating on the same board with the rest of the circuit, and the possibility of adding active devices to the antenna itself to make active antennas. The patch structure is the most common type of microstrip antenna. This kind has been selected owing to its small size, light weight, low cost and ease of fabrication as well as integration with complex circuitry. However, the conventional microstrip patch antenna inherently has a narrow bandwidth and low gain. For this reason, there are many broadband patch antennas that are designed for bandwidth enhancement. Some of the designs include patch with substrate integrated waveguide (SIW), multi-layer and multi-patch designs, different shape with multi slotted patch and so on. However, various shapes of slotted antenna are frequently employed to improve the performance of the antenna because of their structural simplicity [7].

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories: contacting and non-contacting. In the first one, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the second technique, on the other hand, a coupling electromagnetic field is created to transfer power between the microstrip line and the radiating patch. Here, we are concerned with the contacting scheme in implementing an array of microstrip antennas the elements of which can be fed by a single line or multiple lines in a feed network arrangement. The proposed antenna can be implemented using low cost FR-4 substrates and it can maintain accepted and good performance in terms of gain and efficiency. In addition, it has S_{11} response of less than -10dB in the frequency range 22-34GHz. The rest of the paper is organized as follows. Section II describes the design approach of antennas and the behaviour of single element as well as array of multi-elements of microstrip patch antennas aiming for future fifth generation (5G) mobile phone applications. It is also concerned with displaying our simulation results. Finally, section III summaries our concluded remarks.

II Antenna Design and Simulation

2.1. ***Millimeter-Wave Wireless Communication***

Recently, millimeter-wave radio has attracted a great deal of attention from industry and global standardization bodies due to a number of its favorable features to provide multi-gigabit transmission rate. In the near future, it is predicted that mm-wave frequencies could be used to augment the currently saturated 0.70-2.6GHz radio spectrum bands for wireless communications. Since the cost-effective CMOS technology operates well in these bands of frequency spectrum, its combination with high-gain and steerable antennas at the mobile and base station strengthens the viability of mm-wave wireless communications. Additionally, mm-wave carrier frequencies will allow for larger bandwidth allocations and this in turn leads to higher data transfer rates. Furthermore, mm-wave spectrum would permit service providers to significantly expand the channel bandwidths far beyond the present 20MHz channels devoted to 4G users. Owing to increasing the RF channel bandwidth for mobile radio channels, the data capacity is greatly increased, along with extremely decreasing the latency of digital traffic, and thus supporting much better internet-based access and applications that require minimal latency. Moreover, due to their much smaller wavelengths, mm-wave frequencies may exploit polarization and new spatial processing techniques, such as massive MIMO and adaptive beamforming. Finally, as opposed to the disjointed spectrum employed by many cellular operators today, where the coverage distances of cell sites vary widely over three octaves of frequency between 700MHz and 2.6GHz, the mm-wave spectrum will have spectral allocations that are relatively much closer together, making the propagation characteristics of different mm-wave bands much more comparable. Given this significant jump in bandwidth and new capabilities offered by mm-waves, it is evident that this type of waves plays an important role in the new generation of mobile communication technology. In this regard, the 28GHz and 38GHz bands are currently available with spectrum allocations of over 1GHz of bandwidth. However, the mm-wave communication has several propagation characteristics including strong path loss, atmospheric and rain absorption, low diffraction around obstacles and penetration through objects. These propagation characteristics create challenges for next generation wireless networks to support various kinds of emerging applications with different QoS requirements [8, 9].

2.2. ***Single Element Microstrip Patch Antenna***

The microstrip patch antenna is a single layer design which consists generally of four parts (patch, ground plane, substrate, and the feeding part). Patch antenna can be classified as single-element resonant antenna. The patch is a very thin ($\ll \lambda_0$; the free space wavelength) radiating metal strip (or array of strips) located on one side of a thin non-conducting substrate, the ground plane is the same metal located on the other side of the substrate. The metallic patch is normally made of thin copper foil plated with a corrosion resistive metal. Many shapes of patches are designed and the most popular one is the rectangular, square, and circular patch. The substrate layer thickness is 0.01 λ_0–$0.05\lambda_0$. It is used primarily to provide proper spacing and mechanical support between the patch and its ground plane. It is also often used with high dielectric-constant material to load the patch and reduce its size. The substrate material should be low in insertion loss with a loss tangent of less than 0.005. A reference single element microstrip patch antenna is shown in Fig.(2). In the proposed design, the FR-4 substrate was used. The substrate with height of 0.1mm, dielectric constant of 4.35 and a negligible tangent loss was employed. The CST microwave studio tool was used to optimize the dimensions of the newly designed antenna. A metal patch of length (L=2.503mm) and width (W=3.215mm) was connected to 50Ω feed line with an inset on the top of the substrate. The dimensions of inset feed were Li=2.896mm and Wi=0.1928mm.

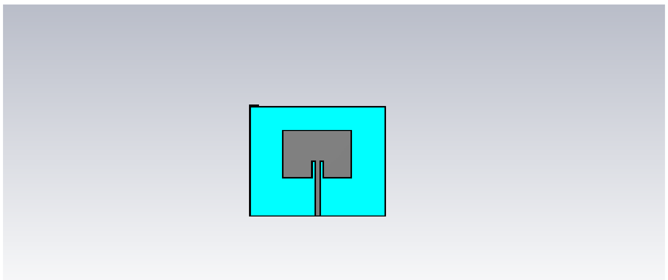

Fig.(2) Single Element antenna front view

Gain of an antenna is defined as its ability to concentrate the radiated power in a given direction or conversely to absorb effectively the incident power from that direction. The term gain describes how much power is transmitted in the direction of peak radiation of an isotropic source. A transmitting antenna with gain of 3dB means that the received power far from antenna will be 3dB higher than the received power from a lossless isotropic antenna with the same input power. The most important parameter to be considered is the maximum transfer of power (matching of the feed line with the input impedance of the antenna). In this regard, S_{11} gives us the insertion loss of antennas. It is a p arameter which indicates the amount of power that is lost to the load and does not return as a reflection. It indicates how well the matching between the transmitter and antenna has taken place. In other words, insertion loss is proportional to the ratio of reflected to the input power of the antenna. Antennas generally radiate efficiently for particular range of frequencies. At these frequencies, the radiated power should be almost equal to input power, i.e., reflected power should very small. Therefore, a graph of S_{11} of an antenna versus frequency is called its return loss curve. For optimum working condition, such a graph must show a dip at the operating frequency and have a minimum dB value at this frequency. So, the expected plot of S_{11} for an antenna would be a flat line throughout the frequency scale with deep dip in the operating frequency range. Fig.(3) shows the simulated result of the underlined antenna indicating that the fundamental resonance frequency is 28GHz with a gain of 6.92 dBi.

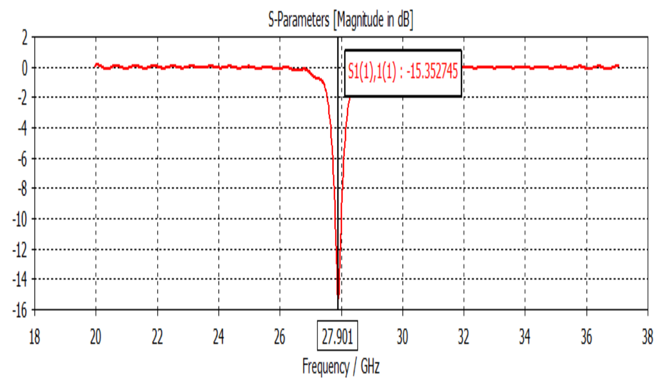

Fig.(3) Simulated S_{11} of the patch antenna resonating at 28GHz

There is another interesting parameter that characterizes the radiation properties of an antenna and distinguishes one antenna from the other. This is the radiation pattern. It is a plot of the far-field of an antenna as a function of the spatial coordinates which are specified by the elevation angle (θ) and the azimuth angle (φ). More specifically, it is a plot of the power radiated from an antenna per unit solid angle. It can be plotted as a 3D graph or as a 2D polar or cartesian slice of this 3D graph. It is an extremely parameter as it shows the antenna's directivity as well as gain at various points in space. It serves as the signature of an antenna and one look at it as often enough to realize the antenna that produced it. The 2D polar plot of the radiation pattern (at φ=90°) is illustrated in Fig.(4) for the examined antenna. The corresponding 3D version of the scene shown in Fig.(4) is displayed in Fig.(5).

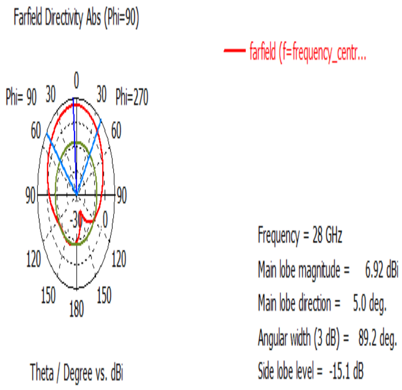

Fig.(4) Single patch antenna radiation pattern at 28GHz, φ=90º

The corresponding 3D version of the scene shown in Fig.(4) is displayed in Fig.(5).

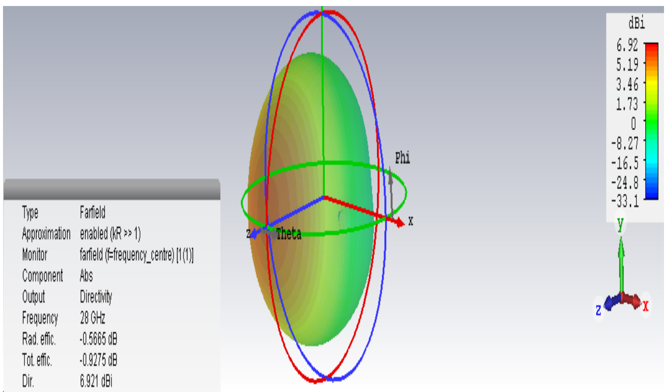

Fig.(5) Single element antenna radiation pattern plot

The power delivered from the transmitter cannot be longer radiated without loss due to incorrect compensation. Some of this power is reflected at the antenna and is returned to the transmitter. The forward and return powers form standing waves with corresponding voltage minima and voltage maxima. This voltage standing wave ratio (VSWR) defines the level of compensation of the antenna. The VSWR is the function of reflection coefficient which depicts the power reflected from the antenna. In this regard, the reflection coefficient is known as S_{11} or return loss. The smaller the VSWR is the better the antenna matched to the transmission line and power delivered to the antenna. In other words, the return loss is generally the amount of power lost in the load. An impedance of exactly 50Ω can be practically achieved at one frequency. The VSWR shows how far the impedance differs from 50Ω with a wide-band antenna. Additionally, the VSWR parameter indicates how efficiently an antenna is operating over the designed range of frequencies. A VSWR ≤ 2 ensures accepted performance. Generally, a VSWR of 1.5 i s standard for mobile communications. Fig.(6) illustrates the VSWR of the proposed antenna and the displayed results demonstrate that the examined antenna possess a VSWR with an acceptable range in the designed frequency band [10].

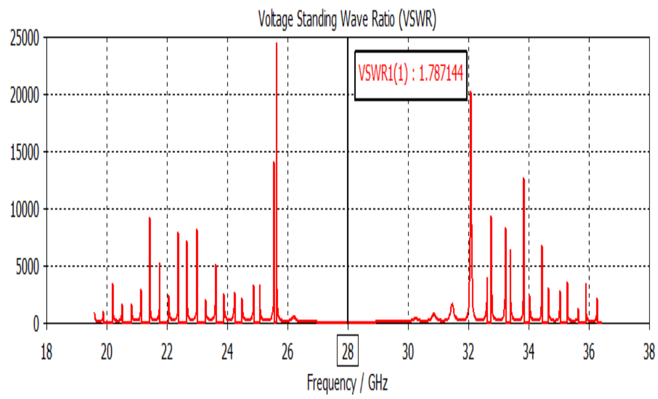

Fig.(6) Single element antenna VSWR plot

The main objective of this work is to increase the gain of the antenna through the implementation of arrays. Initially, single element antenna is transformed to a 2x1 linear array, and finally, we analyze the 4x1 linear antenna arrays to enhance the directivity, gain, and efficiency for the purposes of obtaining better radiation patterns.

2.3. ***Two Elements Microstrip patch antenna***

A modified 2x1 element array microstrip patch antenna is illustrated in Fig.(7). This model is introduced for the purposes of enhancing the performance of the antenna such as increasing its gain, directivity scanning the beam of an antenna system, along with other functions which are difficult to be achieved in the case of single element [7].

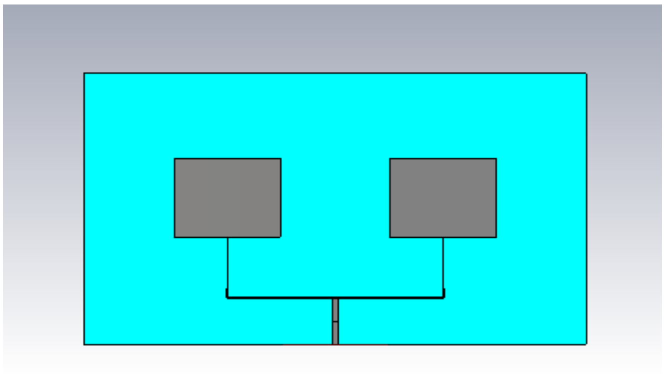

Fig.(7) 2x1 Element array antenna front view

A metal patch of L= 2.472mm and W=3.174mm is connected to 50Ω feed line with an inset, of dimensions Li=0.736mm and Wi =0.1928mm, on the top of the substrate. A microstrip line of 1:2 power divider is used to feed the two antennas and hence the line widths are adjusted according to the power division. Fig.(8) shows the simulated result of the modified 2x1 linear array antenna. This plot displays S_{11} as a function of the operating frequency indicating fundamental resonance of 28GHz.

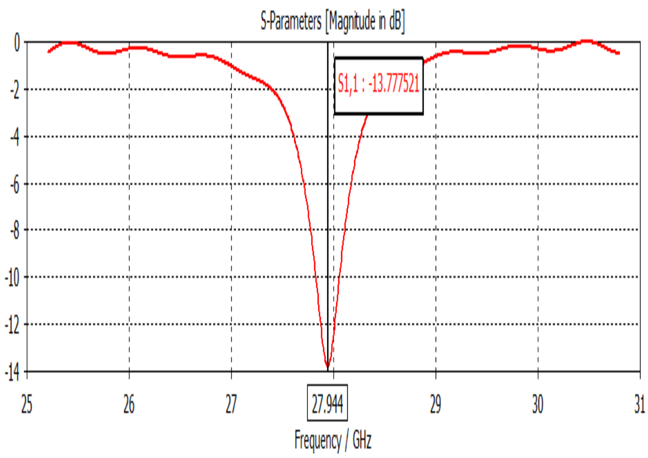

Fig.(8) Simulated S_{11} of the patch array antenna resonating at 28 GHz

The polar radiation plot simulated at ϕ=90° is demonstrated in Fig.(9). Additionally, it has been observed that 2x1 linear array antenna increases the gain by 2.6 dBi.

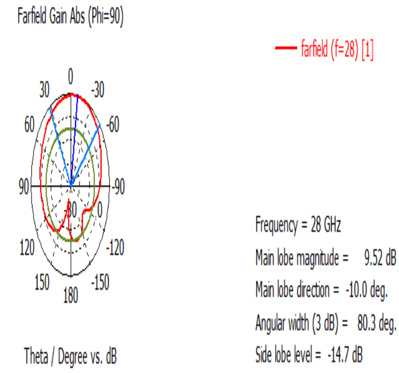

Fig.(9) Antenna radiation pattern at φ=90º

As the single element reference antenna resonates at 28 GHz with the gain of 6.92 dBi whereas with the modified 2x1 linear array antenna increases the gain of the resulting antenna to become 9.52dBi given that the resonant frequency is held fixed at 28 GHz. The 3D radiation pattern of the underlined 2 patch array antenna is traced in Fig.(10), whereas Fig.(11) exhibits its voltage standing wave ratio that exhibits a satisfied practical values at the required operating frequency.

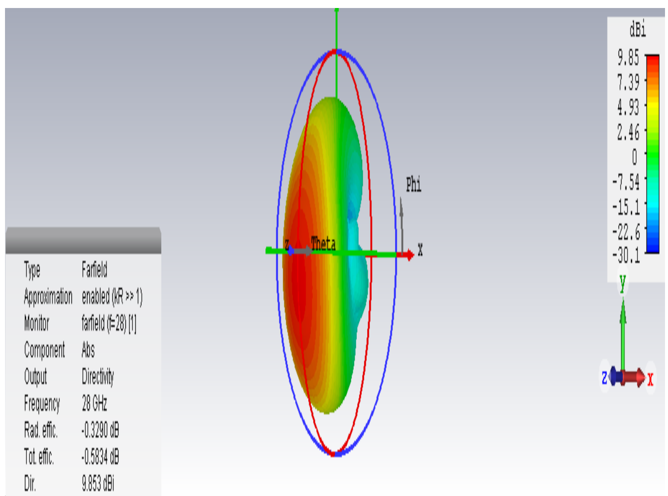

Fig.(10) 2x1 Element array antenna radiation pattern plot.

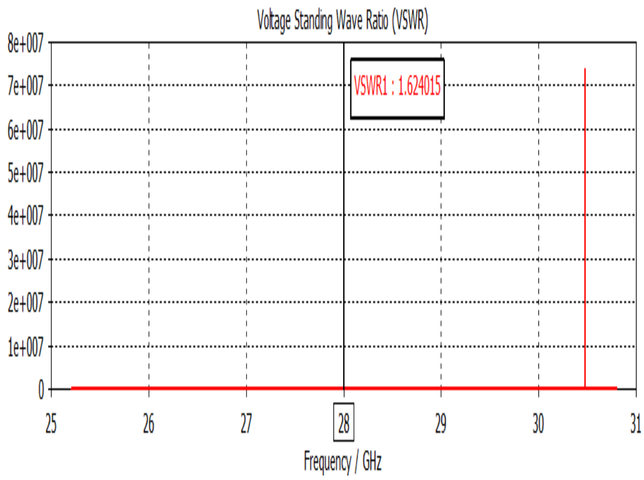

Fig.(11) 2x1 Element array antenna VSWR plot

2.4.Four Elements Microstrip patch antenna

Since the array procedure enhances the behavior of the microstrip patch antenna, we are going to extend the elements of the array to four in order to show to what extent the excess number of elements can improve the performance of the resulting antenna. In the proposed design of 4 elements, it is required to be compatible for the next generation of mobile communication (5G). The constructed antenna is outlined in Fig.(12). Table (I) summarizes the geometry dimensions of the suggested 4x1 element array microstrip patch antenna.

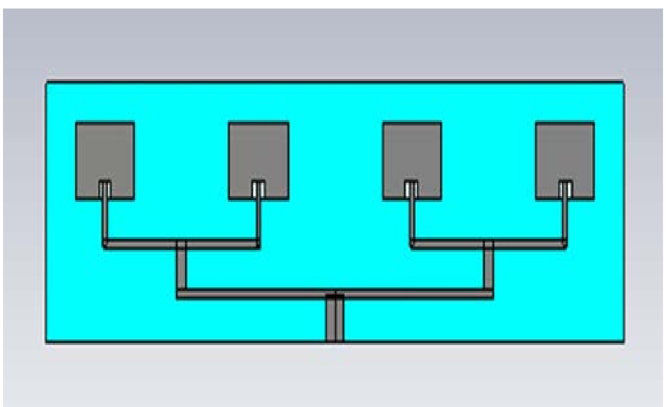

Fig.(12) Proposed 4x1 element array antenna

Parameters	L	W	εr	substrate Height	Fi	ground length	ground width
mm	2.303	3.215	4.35	0.5	0.5556	7.07	31.677

Table (I) Proposed dimension for 4x1 element array antenna

Fig.(13) depicts the S_{11} variations as a function of frequency indicating fundamental frequency of resonance which is near the requested value. The 2D polar plot at φ=90º is as indicated in Fig.(14). The simulated 3D radiation pattern is depicted in Fig.(15) and Fig.(16) describes the VSWR result associated with the examined antenna within reasonable characteristics. Finally, Fig.(17) introduces the realized gain of the proposed new model of patch antenna.

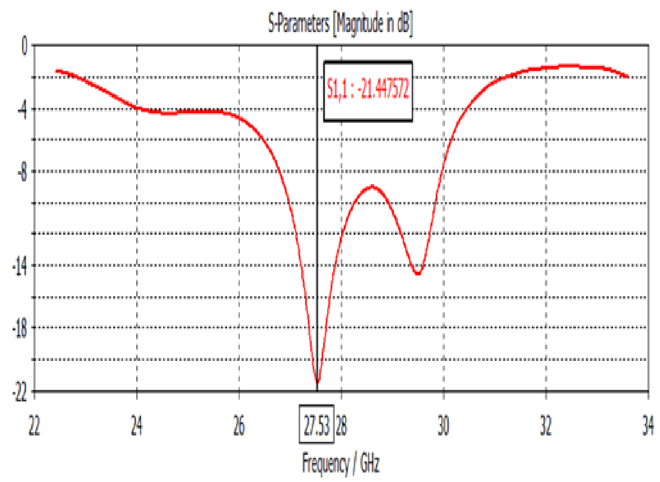

Fig.(13) Simulated S_{11} of the patch antenna resonating at 28GHz

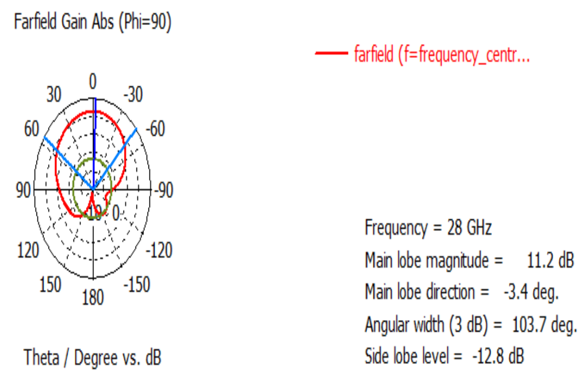

Fig.(14) Antenna radiation pattern at φ=90º

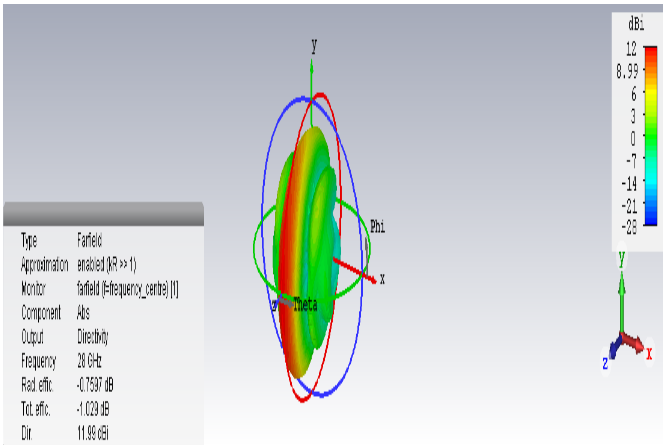

Fig.(15) 3D Radiation pattern of the proposed antenna

From the simulation results, it has been observed that 4x1 linear array antenna increases the gain by 4.34 dBi in comparison with the single element reference antenna as Table (II) demonstrates. As the single element reference antenna resonates at 28 GHz with a gain of 6.86 dBi, whereas with the modified 4x1 linear array antenna, the gain is enhanced to become 11.2 dBi under the same requested resonant frequency, i.e. 28 GHz.

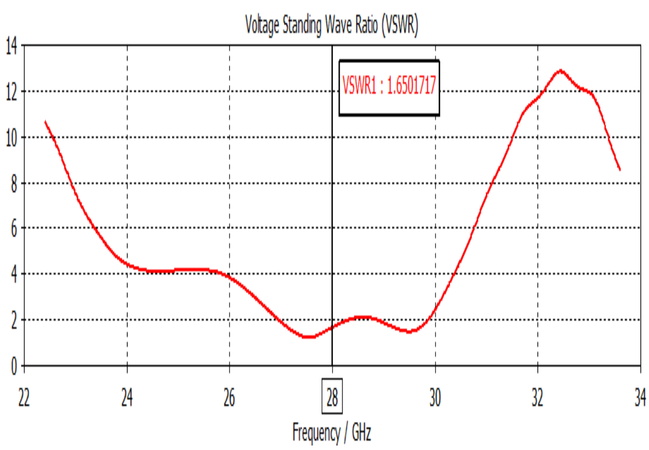

Fig.(16) VSWR for the Proposed 4x1 Element array antenna

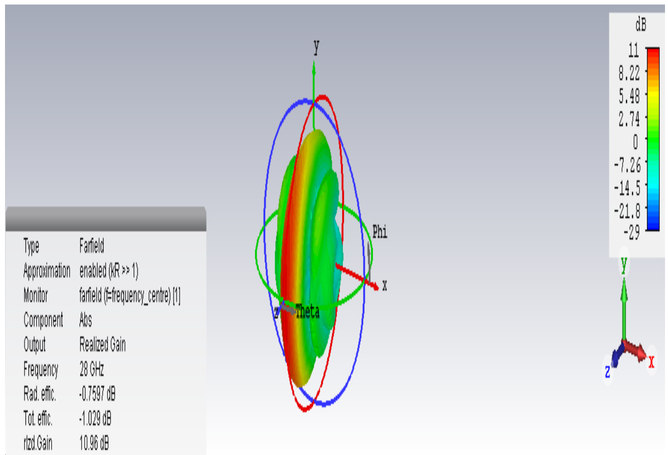

Fig.(17) Realized gain characteristic of the proposed antenna

Parameters Element	Single Element Antenna	2 Elements Antenna Array	4 Elements Antenna Array
S11	- 15.35dB	-13.777dB	-21.44dB
Gain	6.92dBi	9.52dBi	11.2dBi

Table (II) Parameter comparison for different proposed antennas

Different research works are interested in the next generation of mobile communication or future of 5G, especially in the antenna design part [9,10]. The previously proposed antennas have different shapes and characteristics, where they achieve accepted results for antenna parameters. For example, they realized a gain of about 5.29 dB as well as a good radiation pattern. In our proposed antenna, which is designed with the same dielectric constant for FR-4 substrate, the realized gain is higher (10.96 dB). Meanwhile the other literature enhanced the total efficiency through using different shapes such as multiple slot loop antenna. Here, we tested our proposed design of microstrip patch antenna through CST software and Table (III) summarizes our results and outcomes.

Results	S_{11}	Gain(dB)	Directivity (dBi)	Tot.effic (dB)	Rad.effic (dB)
	-21.44	11.23	11.99	-1.029	-0.7

Table (III) Results of proposed antenna

III Conclusions

Antennas for communication systems at 28 GHz are expected to be broadband. They are required to achieve high data rate for the next generation of mobile communication. They should have a high gain to overcome the high path loss at mm-wave frequencies. The high gain antenna provides a wide coverage area for data exchange. In this regard, the microstrip patch antennas are quite and represent an obvious choice for wireless devices due to their low fabrication cost, lightweight and volume, and a low profile configuration as compared to the other bulky types of antennas. This type of antennas is simple and very versatile in terms of resonant frequency, polarization, pattern, and impedance. These antennas can be mounted on the surface of high-performance aircraft, spacecraft, rockets, satellites, missiles, cars, and even handheld mobile telephones. Since the gain obtained by array procedure is much higher than that of single element antenna, a new patch array antenna of four elements aiming for 5G mobile communications is suggested in this paper. Four rectangular elements of microstrip patch antenna have been used to form a uniform array on the cellular hand set PCB. The antenna is designed on a low-cost substrate (FR-4) to operate at 28 GHz. This PCB material has some advantages such as low dielectric tolerance and loss, stable electric property against frequency and thus it is a better choice for high frequency operation. The proposed antenna has good performance in terms of S-parameter, gain, efficiency, and beam steering characteristics. Experimental and simulated results are displayed to validate the usefulness of the proposed patch array antenna for 5G applications. The antenna is designed and stimulated using HFSS software. This proposed 4x1 array antenna has high gain of about 11.2dBi with good impedance matching. The introduced antenna has also reasonable and good characteristics in terms of directivity and VSWR.

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