A 28 Ghz Fr-4 Compatible Phased Array Antenna For 5g Mobile Phone Applications

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Abstract- *This paper presents a small size ultra wideband (UWB) antenna for wireless personal area network applications. The proposed antenna covers the impedance bandwidth of 3.1 to 10.6 GHz frequency range in free space. The design parameters for achieving optimal performance are investigated. A tapered microstrip feeding is employed to enhance the antenna matching. The operation and the characteristics of the proposed antenna are also analyzed. Good agreement has been obtained between the simulation and experimental results. The simulated and measured radiation patterns have demonstrated that the antenna is nearly omni-directional over the entire band.*

Keywords- Antenna , Microstrip , Network applications .

I. INTRODUCTION

In this white paper, we present Straight Path's 5G vision – Gbps Mobility. We begin with our observations of macro information and communications technology (ICT) trends that are relevant to 5G, namely, the convergence of the information technology industry and the communications industry, the innovation throughout the economy spurred by the advancement in ICT, and the making of the ubiquitous broadband infrastructure. Together with globalization, these macro trends are powerful forces that are reshaping the ICT industry yet again and transforming societies and economies worldwide. Amid these macro trends, we believe the mobile industry can thrive by focusing on the strongest and most distinctive value proposition of 5G – a quantum leap in mobile broadband characterized by 1000x capacity increase over 4G and Gbps user experience in a mobile environment. Content, commerce, and mobile Internet of Things (IoT) are among the strongest market drivers for 5G mobile broadband. While content drives mobile traffic growth, mobile commerce increases value added. Mobile IoT, with autonomous vehicles in particular, presents the greatest opportunities for 5G to be a strong catalyst of disruption and to foster new "killer applications" beyond the smartphone.

The fundamental technologies that enable 5G include mmWave, massive MIMO, and small cells. MmWave technologies make it possible to utilize the vast amount of mmWave spectrum for mobile communication; massive MIMO extends the range and increases spectral efficiency in these frequencies by employing a large number of antennas; small cell technologies provide the means to deploy a wide area mobile network with a large number of small cells, scalable backhaul, and proper interference coordination. Collectively, these technologies enable 5G mobile broadband in mmWave spectrum with much larger capacity, much higher data rate, and much denser deployment than 4G.

We also discuss the spectrum bands for 5G, taking into consideration the spectrum needs of 5G, and the tradeoff between spectrum availability and technology feasibility. We believe the prime spectrum for 5G is between 24 GHz and 57 GHz from both the regulatory and technological perspectives. We recommend that the industry prioritizes bands in the 25.25 – 29.5 GHz and the 36 – 40.5 GHz frequency blocks as primary targets to secure for 5G in WRC-19.

As in previous generational evolutions of mobile communication, there should be dual tracks of standardization efforts: one for the ongoing evolution of previous generation and the other for the new generation. We recommend that the industry continue the 4G LTE evolution path under 6 GHz in parallel with 5G standardization for mmWave mobile broadband. The best way to predict the future is to make it happen. Ultimately, 5G is what the industry makes it to be. 5G represents the best opportunity in the next decade for the mobile communication industry to succeed and contribute to the continuing ICT revolution that will touch every human life and transform the world. Along with industry partners and regulatory bodies, Straight Path looks forward to contributing to the success of 5G with our extensive mmWave spectrum portfolio and strong 5G technical expertise.

II. LITERATURE SERVEY

Since the Federal Communications Commission (FCC) [1]authorizes for the unlicensed use of 3.1 GHz – 10.6 GHz frequency band for commercial purpose, UWB technology have attracted huge attention. So far, several design methods and structures have been reported. These UWB antennas with filtering property at the 5–6 GHz band have been proposed not only to mitigate thepotential interferences but also to remove the requirement of an extra band stop filter in the system [2]-[3]. Recently, more and more band-notched UWB antenna designs have been proposed. J. Kim *et al.* proposed a 5.2 GHz notched UWB antenna using slot-type SRR [4]. Lately to generate the frequencyLately to generate the frequency band-notch function, modified planar monopoles antennas with band-notch characteristic have been reported in [5]–[7]. In [5] and [6], different shapes of the slots (i.e. W-shaped and folded trapezoid) are used to obtain the desired band notched characteristics.

Single and multiple [7] half-wavelength Ushapedslits are embedded in the radiation patch to generate the single and multiple band-notched functions, respectively. Some of the research articles are proposed which includes the Bluetooth frequency with UWB spectrum in [8]-[10]. In [8], Yildirim*etal.* experimentally characterized integrated Bluetooth with UWB spectrum, but the extra resonating strip is added to achieve Bluetooth frequency that increase design complexity. Zhan *et al.* proposed an antenna which covers Bluetooth with UWB but the problem is large size. In [10], dual band characteristics with desired bandwidth can be obtained by using a fork shaped radiating patch, whereas, band-notched characteristics can be obtained by etching two L-shaped slots and two symmetrical step slots on the rectangular ground plane. The problem is remains same in terms of size of antenna, design complexity in the above reported antenna [2]-[10].

III. FUNDEMENTALS OF ANTENNA

3.1ANTENNAS:

An antenna is characterized by Webster's Dictionary as "a typically metallic gadget (as a pole or wire) for transmitting or accepting radio waves." The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145–1983) characterizes the antenna or ethereal as "a methods for emanating or getting radio waves." as such the antenna is the provisional structure among free space and a controlling device, as appeared in Figure. The controlling device or transmission line may appear as a coaxial line or an empty pipe (waveguide), and it is utilized to transport electromagnetic energy from the transmitting origin to the antenna, or from the antenna to the collector. In the previous case, we have a transmitting antenna and in the last a getting antenna. A transmission stripeThevenin likeness the antenna arrangement of Figure in the transmitting mode is appeared in Figure where the foundation is spoken to by a perfect generator, the transmission line is spoken to by a line with trademark impedance c, and the antenna is spoken to by a load $Z_A[Z_A = (R_L + R_r) + jX_A]$ with the transmission line.

The Thevenin and the Norton circuit counterparts of the antenna are additionally appeared in Figure. The load resistance RL is utilized to speak to the conduction and dielectric misfortunes connected with the antenna structure while Rr, alluded to as the radiation resistance, is utilized to speak to radiation by the antenna. The reactance XA is utilized to speak to the imagined part of the impedance connected with radiation by the antenna. Under perfect conditions, energy created by the source ought to be completely exchanged to the radiation resistance Rr, which is utilized to speak to radiation by the antenna. Be that as it may, in a down to earth framework there are conduction-dielectric misfortunes because of the lossy way of the transmission line and the antenna, and additionally those because of reflections (mismatch) misfortunes at the interface amongst the line and the antenna. Considering the interior impedance of the source and ignoring line and reflection (mismatch) misfortunes, most extreme influence is conveyed to the antenna under conjugate coordinating.

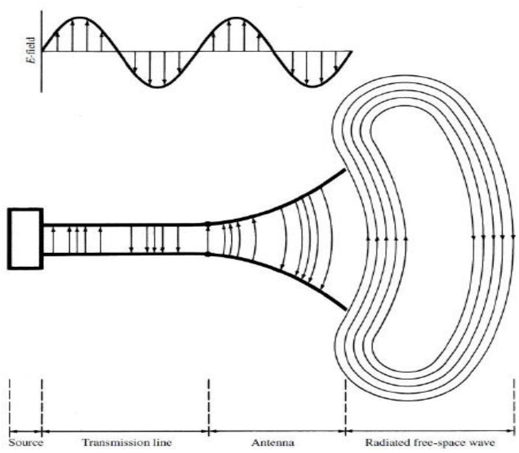


Figure 1: Antenna as a Transition device

The reflected waves from the interface make, alongside the voyaging waves from the source toward the antenna, helpful and damaging obstruction designs, alluded to as standing waves, inside the transmission line which speak to pockets of energy focuses and capacity, average of resonate device. A run of the mill standing wave example is indicated dashed in Figure, while another is exposed in Figure. On the off chance that the antenna system is not legitimately composed, the transmission line could act to an expansive degree as a energy storage component rather than as a wave guide and energy transporting device. On the off accidental that the greatest field forces of the standing wave are adequately expansive, they can bring about curving inside the transmission lines. The misfortunes because of the line, antenna, and the standing waves are undesirable. The misfortunes because of the line can be minimized by selecting low-misfortune lines while those of The antenna can be diminished by decreasing the misfortune resistance spoke to by RL in Figure.

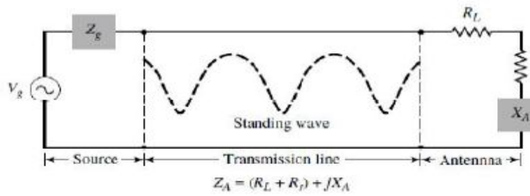


Figure 2: Transmission line thevenin Equivalent Antenna in Transmitting Mode

The antenna can be diminished by lessening the loss resistance spoke to by RL in Figure. The standing waves can be decreased, and the energy storage limit of the line minimized, y coordinating the impedance of the antenna (load) to the trademark impedance of the line. This is the alike as coordinating burdens to transmission lines, where the heap here is the antenna, and is talked about additional in detail in Section. A proportional like that of Figure is utilized to speak to the antenna system in the accepting mode where the source is supplanted by a collector. Every single other portion of the transmission-line proportionate continue as before. The radiation resistance Rr is utilized to speak to in the getting mode the exchange of energy from the empty space wave to the antenna. This is examined in Section and spoke to by the Theven in and Norton circuit reciprocals of Figure. Notwithstanding getting or transmitting energy, a antenna in a propelled remote system is typically required to upgrade or highlight the radiation energy in a few bearings and stifle it in others. In this way the antenna should likewise serve as a directional device notwithstanding a testing device. It should then take different structures to meet the specific need nearby, and it might be a bit of conducting wire, an opening, a patch, a get together of components (array), a reflector, a focal point, et cetera. For wireless communication systems the antenna is a standout amongst the most basic segments. A decent design of the antenna can unwind system necessities and enhance general system execution.

A ride of the mill illustration is TV for which the general communicate gathering can be enhanced by using a superior antenna. The antenna serves to a communication system a similar reason that eyes and eyeglasses help to a human. The field of antenna is energetic and dynamic, and in the course of the most recent 60 years antenna innovation has been an irreplaceable accomplice of the communications revolution. Numerous significant advances that happened amid this period are in like manner utilize today; be that as it may, numerous more issues and difficulties are confronting us today, particularly since the requests for system exhibitions are much more prominent. The initial paper of this extraordinary issue gives a painstakingly organized, exquisite exchange of the key standards of emanating components and has been composed as a presentation for the non master and a survey for the master.

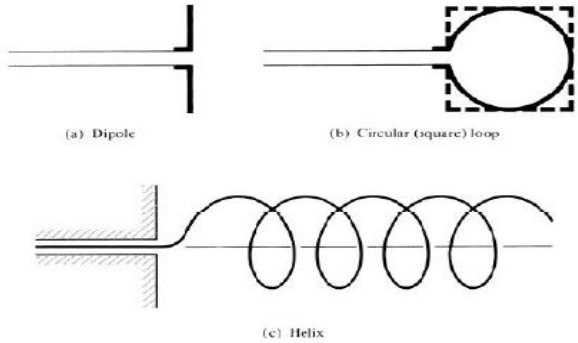


Fig 3: Wire Antenna Configuration

3.2 Omnidirectional Antenna:

In radio correspondence, an omnidirectional antenna is a class of antenna which transmits radio wave control consistently every which way in one plane, with the emanated control diminishing with rise point above or underneath the plane, dropping to zero on the antenna axis. This radiation example is regularly depicted as "donut formed". Take note of this is not quite the similar as an isotropic antenna, which transmits level with power every which way and has a "circular" radiation design. Omnidirectional antenna situated vertically are broadly utilized for an non-directional antenna on the surface of the Earth since they emanate similarly in every single level bearing, while the power transmitted drops off with rise edge so minimal radio energy is pointed into the sky or down toward the earth and squandered. Omnidirectional antenna are generally utilized for radio telecom antenna, and in cell phones that utilization radio, for example, PDAs, FM radios, walkie-talkies, remote PC systems, cordless telephones, GPS and in addition for base stations that speak with mobile radios, for example, police and taxi dispatchers and air ship communications.

Figure 4: Omnidirectional Antenna

3.3 Wireless Communication:

IEEE **802.11** is an arrangement of guidelines for implementing wireless local area network (WLAN) PC transmission in the 2.4, 3.6, 5 and 60 GHz bands of frequency. They are executed and kept up by the IEEE LAN/MAN Standards Committee. The 802.11a standard utilizes the same data link layer protocol and frame format as the actual standard. It operates in the 5 GHz band with a greatest net information rate of 54 Mb/s, plus error correction code, compliant reasonable net achievable throughput in the middle 20 *Megabyte*per second. Since the 2.4 GHz band is intensely used to the point of being excessively swarmed, utilizing the moderately unused 5 GHz band gives 802.11a a consequential advantage. In principle, 802.11a signals are absorbed extra promptly by walls and further strong stuffs in their way attributable to their littler wavelength. 802.11a additionally experiences interference, however locally there might be less signals to interfere with, thus output in less interference and better throughput.

The Microstrip patch antennas are outstanding for their execution and their strong outline, fabrication and their widespread utilization. The merits of the Microstrip patch antenna have defeat their de-merits,for example, light weight, simple to design and so on., the applications are in the dissimilar fields for example, in the satellites, medical applications, and even in the military systems like in the airplanes, missiles, rockets, and so on.,The utilization of the Microstrip antennas are spreading in every one of the fields and territories and now they arepicking up notoriety in the commercial aspects for of the low cost of the substrate material and fabrication. It is additionally anticipated that that due would the expanding utilization of the fix radio wires in the wide range it could assume control over the utilize of the customary recieving wires for the most extreme applications. Microstrip patch antenna has numerous applications some of which are examined as underneath.

3.3.1 MOBILE AND SATELLITE COMMUNICATION APPLICATION:

Mobile communication needs low-cost, small, low profile antennas. Microstrip patch antenna has every one of these prerequisites and altered sorts of microstrip antenna have been intended for use in versatile communication systems. For satellite circularly spellbound radiation examples are required and can be acknowledged utilizing either square or roundabout patch with one or two feed points.

3.3.2 GLOBAL POSITIONING SYSTEM APPLICATIONS:

These days microstrip patch antennas with substrate giving high permittivity sintered material are being utilized for worldwide situating systems. These antennas are circularly energized, compact and extremely costly because of their situating. It is expected that millions of GPS receivers will be utilized by the general community for land vehicles, maritime vessels air ship to discover their position accurately.

3.3.3 RADIO FREQUENCY IDENTIFICATION (RFID):

RFID utilizes as a part of various areas like mobile communication, fabricating, coordinations, health care and transport. RFID system generally utilize frequencies between 30 Hz and 5.8 GHz relying upon the applications. Fundamentally RFID system is a transponder or tag and a handset or likewise peruser.

3.3.4 WORLDWIDE INTEROPERABILITY FOR MICROWAVE ACCESS (WIMAX):

The IEEE 802.16 standard is additionally called WiMax. It comes upto 30 mile radius hypothetically and information rate of 70 Mbps.MPA creates three resounding modes at 2.7, 3.3 and 5.3 GHz and is thus utilized in WiMax compliant communication gear.

3.3.5 RADAR APPLICATION:

Radar is utilized for distinguishing affecting targets case individuals and vehicles. It requires a position of safety, light antenna subsystem, the microstrip antenna are the perfect decision. The manufacture innovation depends on photolithography and empowers the mass creation of microstrip antenna with repeatable execution at a lower cost in a lesser time when compared with the customary antenna.

3.3.6 RECTENNA APPLICATION:

Rectenna is an extraordinary sort of antenna, a correcting antenna that is utilized to specifically change over microwave vitality to DC control. Rectenna is a creation of four subsystems i.e. antenna, post correction channel, rectifier, metal amendment channel. In rectenna application, it is fundamental to outline antenna with high order attributes to fulfill the requests of long- distance links. Since the primary point of utilizing the rectenna is to exchange DC control through remote connections for a long separation, it must be proficient by expanding the electrical size of the antenna.

3.3..7 TELEMEDICINE APPLICATION:

Antenna is working at 2.45 GHz adversary telemedicine application. The wearable microstrip Antenna is utilized for Wireless Body Area Network (WBAN). The planned Antenna accomplishes a front to back back ratio and gain as compared to the alternate antennas, as additionally the semi directional radiation pattern which is favored over the omni-directional example to anticipate undesired radiation to the client's body and fulfills the prerequisite for on-body and off-body applications. An antenna having a gain of 6.7 dB and a Front to back ratio of 11.7 dB reverberating at 2.45GHz is favored for telemedicine applications.

3.3.8 MEDICINAL APPLICATIONS OF PATCH:

It is inquired about that in the handling of harmful tumors. The microwave energy is the best method for instigating hyperthermia in the patient. The outline of the specific radiator that is utilized for this reason ought to have light weight and simple in taking care of furthermore tough. Just the patch radiator satisfies every one of these necessities. The underlying examples for the Microstrip radiator for initiating hyperthermia depended on the printed dipoles and annular rings which were composed in view of S-band. Later the plan depended on the round microstrip disk at L-band. There is a basic operation that is incorporated with the instrument; two coupled Microstrip lines are isolated with an adaptable partition that is utilized to quantify the temperature inside the human body. In this work, our goal was to design a triangular and rectangular microstrip patch array working at 1.7GHz for wireless applications. Its focal points over traditional triangular and rectangular single patch microstrip antenna working at a similar frequency was investigated and discussed.

3.4 ANTENNA PARAMETERS:

3.4.1 RADIATION POWER DENSITY:

Electromagnetic waves are utilized to transport data through a guiding structure or a wireless medium, from one point to the other. It is then common to assume that power and energy are connected with electromagnetic fields. The amount utilized to label the power connected with an electromagnetic wave is the prompt Poynting vector defined as

$\omega = \xi \times \mathrm{N}$

ω= instantaneous Poynting vector (W/m2)

N = instantaneous magnetic-field intensity (A/m)

ξ = instantaneous electric-field intensity (V/m)

3.4.2 DIRECTIVITY:

In the 1983 variant of the IEEE Standard Definitions of Terms for Antennas, there has remained a substantive change in the meaning of directivity, compared to the meaning of the 1973 form. Fundamentally the term directivity in the fresh 1983 form has been utilized to replace the term directive gain of the ancient 1973 form. In the novel 1983 form the term directive gain has been expostulated. . As per the creators of the new 1983 principles, "this change aligns this standard in line with common utilization among antenna engineers and with other international standards, prominently those of the (IEC)." Therefore antenna is describe as "the ratio of the radiation power in a provided guidance from the antenna to the radiation intensity middle value of over all directions. The usual radiation intensity is equivalent to the aggregate power radiated by the antenna divided by 4π. If the directions are not specified, the direction of most extreme radiation power is suggested." Stated all the more basically, the directivity of a non-isotropic basis is equivalent to the ratio of its radiation intensity in a provided guidance over that of an isotropic source. In mathematic form, it can be written as

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}}$$

If the direction is not indicated, it infers the direction of maximum radiation intensity (maximum directivity) expressed as

$$D_{\max} = D_0 = \frac{U_{\max}}{U_0} = \frac{4\pi U_{\max}}{P_{rad}}$$

D=directivity (dimesionless)

Uo = radiation intensity of isotropic source (W/unit solid angle)

D_0=maximum directivity (dimensionless)

Prad=total radiated power (W)
U = radiation intensity (W/unit solid angle)
Umax=maximum radiation intensity (W/unit solid angle)

3.4.3 BEAM WIDTH:

Connected with the pattern of an antenna is a parameter assigned as beam width. The beam width of a pattern is characterized as the angular separation amongst two indistinguishable points on inverse side of the pattern maximum. In an antenna pattern, there are a various beam widths. Any of the most generally utilized beam widths is the Half-Power Beam width (HPBW), which is characterized by IEEE as: "In a plane containing the bearing of the maximum of a beam, the edge between the two headings in which the radiation intensity is one-half approximation of the beam." This is exhibited in Figure. Another important beam width is the angular separation b/w the first nulls of the pattern, and it is alluded to as the First-Null Beam width (FNBW).

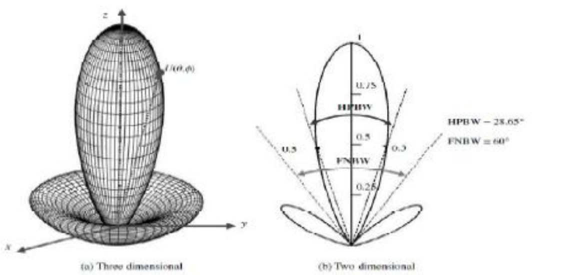


Figure 5: Two and Three-dimensional power patterns(in linear scale) U(Θ)=cos2(ө)cos2(3ө).

Both the HPBW and FNBW are shown for the pattern in Figure for the pattern of Other beam widths are those where the pattern is −10 dB from the most extreme, or whatever other esteem. However, the term beam width, in practice, with no other identification, as a rule alludes to HPBW. The beam width of an antenna is a vital figure of merit and often is utilized as a trade-off amongst it and the side lobe level; that is, as the beam width diminishes, the side lobe increments and vice versa. Furthermore, the beam width of the antenna is similarly utilized to depict the resolution capabilities of the antenna to distinguish b/w two radar targets or adjacent radiating sources. The most widely resolution criterion expresses that the resolution capability of an antenna to distinguish b/w two sources is equal to half the first-null beam width (FNBW/2), which is usually utilize to approximate the half power beam width (HPBW). i.e. two foundations separated by angular distances greater or equal than FNBW/2 ≈ HPBW of an antenna with a unchanging dissemination can be resolved. If the the partition is littler, then the antenna will tend to smooth the angular separation distance.

3.4.4 GAIN:

Another valuable measure describing the execution of an antenna is the gain. Although the gain of the antenna is firmly identified with the directivity, it is a measure that takes into considers the efficiency of the antenna as well as its directional abilities. Keep in mind that directivity is a measure that describes just the directional belongings of the antenna, and it is consequently controlled only by the pattern. Gain of an antenna (in a provided guidance) is defined as "the ratio of the intensity, in a certain direction, to the radiation intensity that would be gotten if the power acknowledged by the antenna were radiated isotropically. The radiation intensity comparing to the isotropically radiated power is equivalent to the power accepted (input) by the antenna divided by 4π." In condition form this can be communicated as

$$Gain = 4\pi \frac{radiation\,intensity}{total\,input(accepted)\,power} = 4\pi \frac{U(\theta,\phi)}{P_{in}}(\text{dimensionless})$$

In most time we deal with relative gain, which is characterized as "the ratio of the power gain in a provided direction to the power gain of a source antenna in its referenced direction." The power input must be the same for both antennas. The reference antenna is normally a dipole, horn, or any further antenna whose gain can be calculate or it is known. As a rule, however, the reference antenna is a lossless isotropic source. . In this manner

$$G = \frac{4\pi U(\theta,\phi)}{P_{in}(lossless\,isotropic\,source)}(\text{dimensionless})$$

At the point, the direction is not expressed,the power gain is generally taken in the direction of maximum radiation.

3.4.5 VSWR:

At the point a transmission line (cable) is ended by impedance that does not coordinate the characteristic impedance of the transmission line, not the greater part of the power is consumed by the termination. Part of the power is reflected down the transmission line. The front (or incident) signal mixes with the back (or reflected) signal to cause a voltage standing wave design on the transmission line. The ratio of the max to min voltage is recognized as VSWR, or Voltage Standing Wave Ratio.

$$VSWR = \frac{1+\Gamma}{1-\Gamma}$$

3.4.6 BEAM EFFICIENCY:

Another parameter that is oftentimes used to judge the nature of transmitting and receiving antennas is the beam efficiency. For an antenna with its real lobe directed along the z-axis (θ = 0), the beam efficiency (BE) is defined by

$$BE = \frac{powertransmitted(received)withinconeangle\theta_1}{powertransmitted(received)bytheantenna}(\dim ensionless)$$

Where θ1 is the half-angle of the cone within which the percentage of the total power is to be found. Equation can be written as

$$BE = \frac{\int_0^{2\pi}\int_0^{\theta_1} U(\theta,\phi)\sin\theta d\theta d\varphi}{\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta d\theta d\varphi}$$

If θ1 is picked as the angle where the first null or minimum happens then the beam efficiency will demonstrate the amount of power in the significant lobe equated to the total power. A very extraordinary beam efficiency (b/w the nulls or minimums), frequently in the high 90s, is fundamental for antennas utilized in radiometry, radar, astronomy, and other applications where received signals via the minor lobes must be minimized.

3.4.7 RETURN LOSS:

The Return Loss of a line is the proportion of the power reflected once again from the line to the power transmitted into the line. It is usually communicated in dB.

RL= –20log Γ Db

For perfect matching amongst the transmitter and the antenna, *RL* = ∞ which means no power would be returned back, and Γ = 0 whereas a Γ = 1 has a *RL* = 0 dB, which implies that alloccurrence power is reflected.

3.4.8 INPUT IMPEDANCE:

Input impedance is characterized as "the impedance introduced by an antenna at its terminuses or the ratio of the voltage to current at a couple of terminals or the ratio of the appropriate segments of the electric to magnetic fields at a point." In this segment we are primarily involved in the input impedance at a pair of terminals which are the input terminals of the antenna. These terminuses are designated as a − b. The ratio of the voltage to current at these terminals, with no load attached, characterizes the impedance of the antenna.

IV. SIMULATION RESULTS AND ANALYSIS

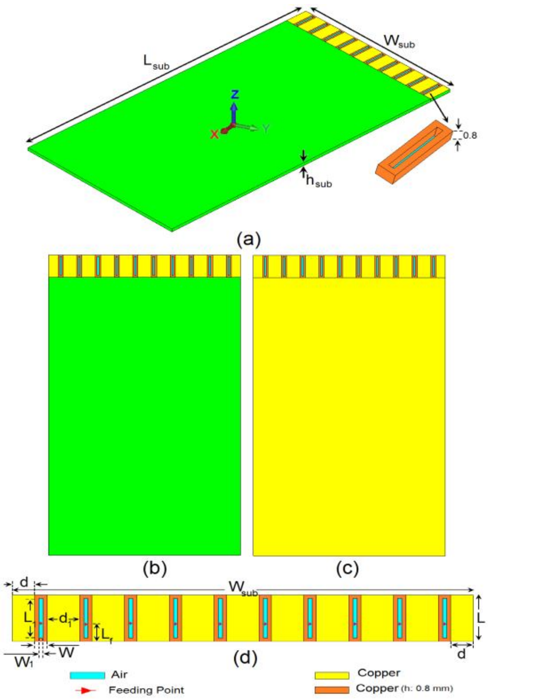


Fig. 2. Proposed 5G mobile-phone antenna configuration, (a) side view, (b) top layer, and (c) bottom layer, and (d) Geometry of the antenna array.

TABLE I FINAL DIMENSIONS OF THE 5G ANTENNA PARAMETERS

Parameter	W_{sub}	L_{sub}	h_{sub}	W	L
Value (mm)	55	110	0.8	1.5	7
Parameter	W_1	L_1	d	d_1	L_f
Value (mm)	0.5	6	3.1	4.35	2.85

Conventionally, the microstrip slot antenna (MSA) consists of a radiation element that is formed by cutting a narrow slot in a metal plate. The length of slot (*a*) is a half wavelength andthe width (*b*) is a small fraction of a wavelength. This type ofantenna is called the complementary dipole antenna

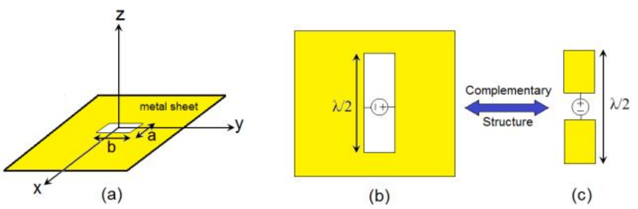


Fig. 3. (a) Side view of the conventional slot antenna configuration, (b)
slot antenna (complementary dipole), (c) dipole antenna

Configurations of the conventional slot antenna and its complementary structure are illustrated in Fig. 3. In this study, we started by designing a conventional slot antenna for

28 GHz. In order to improve the antenna performance and also eliminate the effect of high-loss FR-4 substrate, the reonator of the slot structure has been converted to the air-filled slotloop structure with a thickness of hsub. Configurations of the 28 GHz conventional-slot and slot-loop antennas are illustrated in Fig. 4. Figure 5 illustrates the simulated S11 characteristics of the conventional slot and proposed slot-loop antennas (descret-port feeding has been used to feed the antennas in the simulations.). It can be seen that both of the antennas have very similar respone.

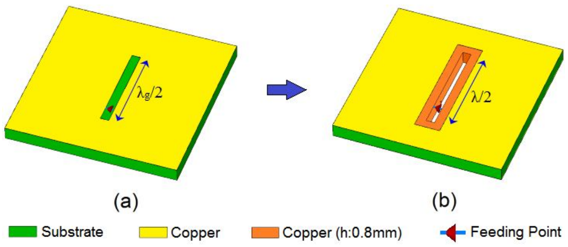
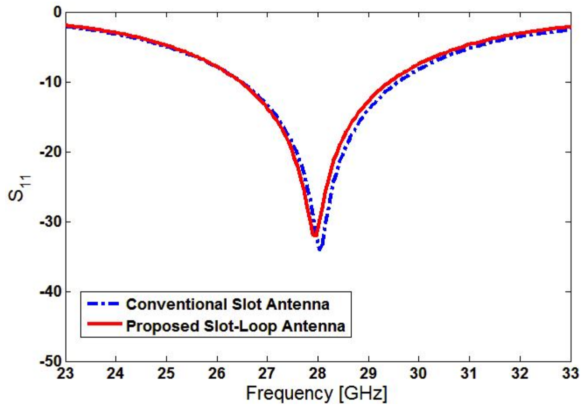
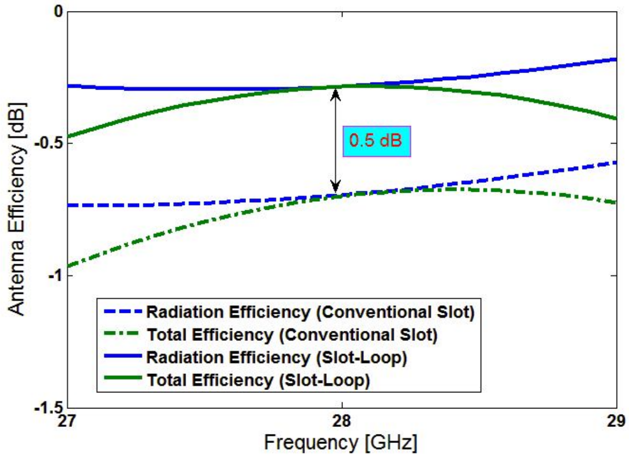
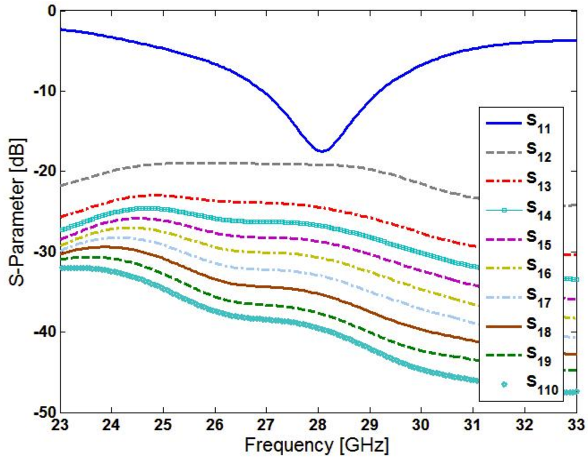


Fig. 4. Geometry of, (a) conventional slot antenna, and (b) proposed slotloop antenna.

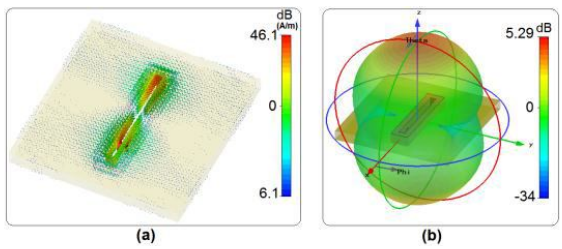
the radiation and total efficiencies of the antenna shown in Fig. 4. As illustrated in Fig. 6, by sing the proposed design (slot-loop antenna), the antenna efficiencies can be improved by about 0.5 dB in the band from 27 GHz to 29 GHz. And the radiation and total efficienciesare the same at the center frequency.





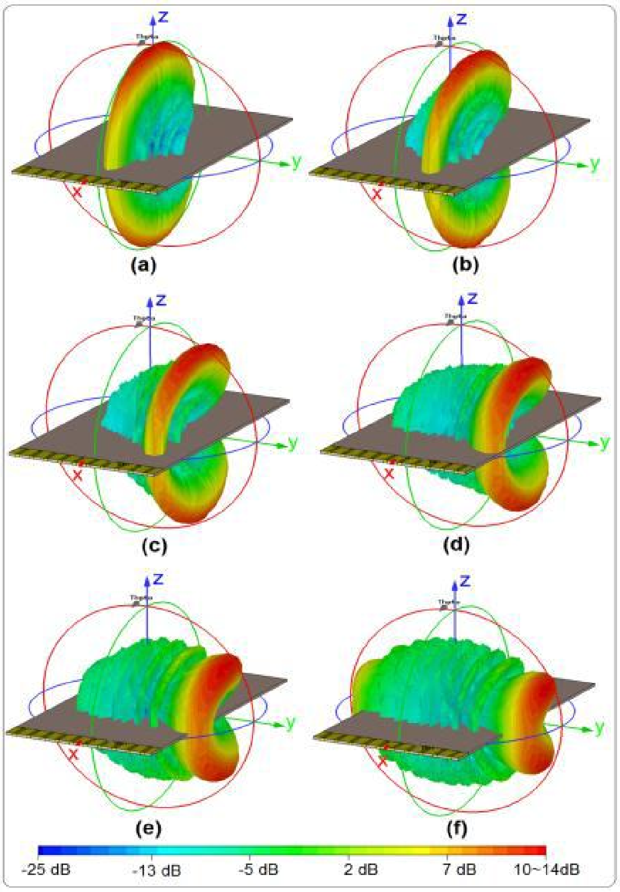


As illustrated, the current have concentrated on the edge regions of the mobile phone PCB and most of the current flows are distributed around of the slot-loop elements. Furthermore the effect of the full ground plane on the power of radiation is not significant. The simulated S-parameters of the proposed structure is illustrated in Fig. 9. It can be see that the highest mutual-coupling characteristic between theelements are less than -18 dB which are sufficient for beam



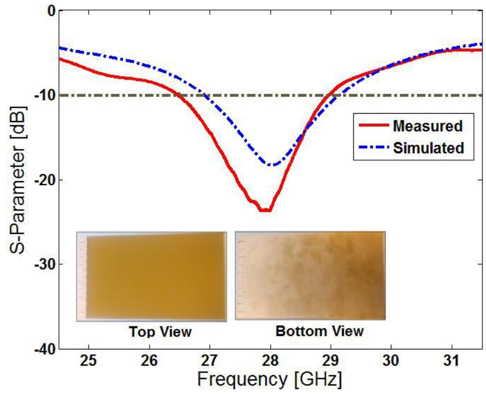
the simulated current distributions for the slot-loop antennas at 28 GHz. As illustrated that most of the currents flow around the slot-loop resonator. In addition, the simulated 3D radiation pattern of the proposed single antenna element is illustrated in Fig. 7(b). It can be seen that the antenna has a good radiation behaviour with 5.29 dB realized gain at 28 GHz.

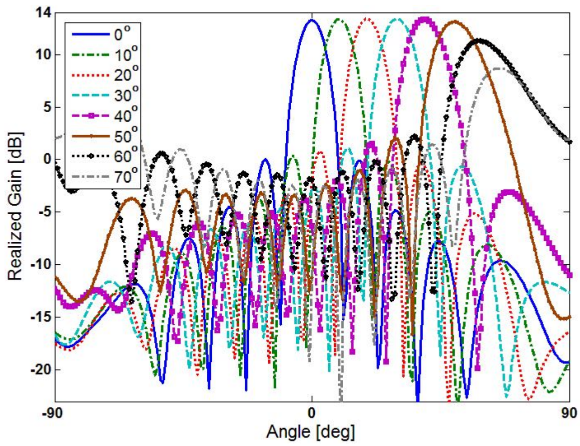
The configuration of the proposed beam steerable antenna for mobile phone applications is shown in Fig. 2. The surfacecurrent distribution for the antenna at 28 GHz



Simulated 3D radiation patterns of each array for different scanning angles, (a) 0o, (b) 15o, (c) 30o, (d) 45o, (e) 60o, and70.

The beam steering characteristic of antenna radiation patterns in different scanning angles at 28 GHz is shown in Fig. 10. As seen, the proposed antenna has a good beam steering property which is highly effective to cover the range of ±70o. The beam-steering characteristic of the proposed antenna for plus/minus (+/-) scaning angles are symertric. Figure 11 illustrates the simulated realized gains of the antenna. As seen, the antenna has a good gain levels indifferent scanning angles. For the scaning range of 0 to 50degree the antenna has a consistant gain of about 13 dB.





V. CONCLUSION

In this paper, a new air filled slot-loop phased array antenna aiming for 5G mobile communications is presented. The antenna is designed on a low-cost substrate (FR-4) to operate at 28 GHz. Ten elements of slot-loop antenna elements have been used for form a uniform linear array on the top region of the cellular handset PCB. The proposed antenna has good performance in terms of S-parameter, gain, efficiency, and beam steering characteristics. Experimental and simulated results are presented to validate the usefulness the proposed phased array antenna for 5G applications.

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