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COMMUNICATIONS

Impact of Substrate Thickness on the Rectangular Patch Antenna for 5G Communication System by CST Studio

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ABSTRACT

An antenna is of extensive significance for a conversation device because the layout of an air interface is specifically reliant at the antenna layout. With the significant wireless evolution from 1G to 5G, technologies and network capacities are also evolving to full-fill the promptly growing customer demands. These continually increasing demands have gone concurrently with extensive technological accomplishments of the antenna design community. This paper discusses fifth-generation (5G) smart antennas, presents design of an efficient micro-strip antenna for 5G communication systems and the antenna is designed on low-loss Teflon based RT/duroid 5880 substrate with (ε_r) of (2.2) and a $(tan\delta\ = 0.0009)$, to wrap things up, and presented a comparative study of effect of height in the performance parameters of rectangular shaped micro-strip patch antenna, the antennas were simulated for purpose of the application of wireless LAN for $(f_r = 28\ GHz\ )$ using CST Microwave Studio software, the performance of the designed antenna was analysed in terms of bandwidth, gain, return loss, voltage standing wave ratio, and radiation pattern (3D), the conclusion showed that the submitted designs have a bandwidth of $(10\ dB)$ greater than $(2\ GHz)$, with an achieved total gain of more than $(10\ dB\ )$, the performance of the proposed antenna satisfies the requirements of 5G communications systems in terms of high gain, high radiation efficiency and adequate bandwidth.

تأثير سماكة الركيزة على هوائي التصحيح المستطيل في الجيل الخامس للاتصالات باستخدام CST

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الملخص

يعتبر الهوائي احد العناصر الأساسية في منظومات الاتصالات الحديثة ، حيث يعتمد تصميمه بشكل أساسي على نوع الهوائي وطريقة التصميم المستخدمة . التطور في نظم الاتصالات المتنقلة والشبكات من الجيل الأول الى الجيل الخامس يهدف الى تلبية متطلبات العملاء المتزايدة لتحقيق السرعة التي هي من سمات العصر الحديث ، لقد تزامنت الاحتياجات مع الإنجازات التكنولوجية الواسعة لمهندسي الاتصالات والتقنية ، في هذه الورقة تم دراسة وتحليل لنوع من الهوائيات المستخدمة في الجيل الخامس للاتصالات المتنقلة، حيث تم تصميم هوائيات micro-strip فعالة لأنظمة اتصالات الجيل الخامس ، وهي مصممة على ركيزة RT / duroid 5880 ذات فقد منخفضة ومصنوع من مادة التفلون مع $(\varepsilon_r = 2.2)$ ، و $(tan\delta = 0,0009)$ ، وأجريت مقارنة لتأثير التغير في الارتفاع لركيزة على أداء الهوائي الشريحي المستطيل الشكل ، كما تمت محاكاة الهوائيات لغرض التطبيق على الشبكة المحلية اللاسلكية لتردد الرنين $(28GHz)$ باستخدام برنامج CST Microwave Studio ، تحليل أداء الهوائي المصمم من حيث عرض النطاق الترددي والكسب والفقد الراجع و VSWR ونمط الإشعاع (3D) ، وأظهرت النتائج أن التصميمات المقدمة لها عرض نطاق أكبر من $(2GHz)$، مع تحقيق كسب إجمالي يزيد عن $(10dB)$ ، وهذا يلبي أداء الهوائي المصمم للاتصالات الجيل الخامس مع كسب عالي وكفاءة الإشعاع عالية وعرض النطاق جيد.

الكلمات المفتاحية

الجيل الخامس
الركيزة
الكسب
الهوائي

Introduction

Mobile and wireless networks have made tremendous growth in the past last years. Although higher data rates have been achieved with 4G/LTE standards, however, exponentially growing data rate requirements led by the rapidly increasing number of wireless devices, instigated substantial development in establishing fifth-generation (5G) standards for commercial mobile and broadband wireless communication services[7] , In order to take advantage of the steady technological development in communications, integrated level antennas have gained a lot of attention in recent years for mm Wave applications, because of their low cost, ease of manufacture and high efficiency. Any construction of antennas is physically small and at the same time large enough electrically to radiate efficiently [1]. The usefulness of the study is illustrated by an improved flat antenna design for 5G communication systems. The design characteristics of the proposed antenna in the 28GHz range where the antenna has a broadband width greater than 2 GHz and an impedance has 50 Ω, the proposed antenna has high radiation efficiency to compensate for the additional loss of millimetres wave frequencies [4]. The objective of this paper

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is to study and analysis of the characteristics of patch antenna for 5G communications systems, and comprehensive evaluation of the various parameters supported by antenna performance (antenna type, antenna efficiency, frequency range and feeding technique, fixed substrate electrical insulation, substrate thickness, substrate loss touch, etc....) [3].

Literature reviews

The eventual goal of the forthcoming 5G wireless networking is to have relatively fast data speeds, incredibly low latency, substantial rises in base station efficiency, and major changes in expected Quality of Service (QoS) for customers relative to the existing 4G LTE networks. this paper briefly discusses the architecture of 5G, followed by the security associated with the 5G network, 5G as an energy-efficient network, various types of efficient antennas developed for 5G, and state-of-the-art specifications for IoT applications along with their related communication technologies [9].

The height of the dielectric substrate material for a microstrip patch antenna is utterly important in terms of controlling bandwidth as well as a surface wave, it presented a comparative study of the effect of height in the performance parameters of rectangular-shaped microstrip patch antenna, the antennas were simulated for purpose of the application of wireless LAN for resonance frequency (2.45GHz), five antennas with different heights were designed using same dielectric substrate material with relative permittivity of 2.84 for the analysis of their performances. this study was carried out by using FEKO, Electromagnetic solver software that uses the Method of Moments (MoM) technique, concluding that, a substrate with greater height can be used to achieve better directivity [10].

An antenna has been designed to operate on one band of (5.5 GHz), and choosing one band prevents interference and improves the band that works for the WiFi application the bandwidth can be achieved by removing the frequency spectrum adjacent to the band to prevent interference and improve the edge of the band, note that the bandwidth decreases when the ground level width acquires a reasonable value when it becomes approximately greater than the correction width or is close to twice the correction width[11].

The design and development of a compact tapered slot antenna (TSA) for the fifth generation (5G) phased array communications is described in this manuscript, the proposed low-profile TSA element is designed on a Rogers RT5880 (ε=2.2 and δ=0.0009) dielectric to work in the frequency range from (21 to 23 GHz). the results show that the proposed design provides good characteristics in terms of S-parameters, antenna gain, efficiency, SAR, and beam steering, which fit the need of 5G cellular communications [12].

Present a novel printed monopole antenna for ultra-wideband applications, the proposed antenna consists of a square radiating patch with an inverted T-shaped slot and a ground plane with an inverted T-shaped conductor-backed plane, which provides a wide usable fractional bandwidth of more than 130% (2.91-14.1 GHz). the designed antenna has a small size of (12 × 18 〖mm〗^2) , and simulated and experimental results obtained for this antenna show that it exhibits good radiation behaviour within the UWB frequency range[13].

This manuscript proposes a new design of phased array antenna for future fifth generation (5G) cellular communications. the proposed phased array antenna is designed on a low-cost N9000 PTFE substrate with overall size of (60×130×0.8 〖mm〗^3) , the proposed phased array antenna has good gain, efficiency, and (3D) beam steering characteristics in the entire operation band, which makes it suitable for millimeter-wave 5G communications [14].

Research work presents another design of a multi-input multi-output (MIMO) antenna with dual wide operating bands at the millimeter-wave (MMW) region proposed for 5G applications. the design consists of two monopole elements with full size of (26 × 11 〖mm〗^2), the two monopoles are designed to provide dual-band operation at the frequencies 27 GHz and 39 GHz, the proposed MIMO manifests acceptable gain that reaches (5 dBi) and (5.7 dBi) in the first and second bands, respectively, while the radiation efficiency reaches 99.5% and 98.6% over the first and the second bands, respectively. the MIMO performance is also studied where a very low envelope correlation of about (〖10 〗^(-4))is obtained and a diversity gain of about (10 dB) over the two operating bands is also achieved [15].

This paper designs simulates, and analyses the S-band microstrip patch antenna (MPA) for wireless applications. FR-4 (lossy) and Rogger RT/duroid, whose dielectric permittivity is 4.3 and 2.2, respectively, have been used as substrate materials. Simulation is done by computer simulation technology (CST) suite studio 2019 software. Simulations with FR-4 material showed that the return loss was -20.405 dB, the gain was 2.592 dB, the directivity was 7.47 dBi, the voltage standing wave ratio (VSWR) was 1.221, the bandwidth (BW) was 0.0746 GHz, and the efficiency was 34.69%. Also, Rogers RT/duroid material gives results of a return loss of -12.542 dB, a bandwidth (BW) of 0.0349 GHz, a gain of 8.092 dB, a directivity of 8.587 dBi, and an efficiency of 94.24% [16].

Propose an eight-port/four-resonator slot antenna array with a dual-polarized function for multiple-input-multiple-output (MIMO) 5G mobile terminals, the design is composed of four dual-polarized square-ring slot radiators fed by pairs of microstrip-line structures, the radiation elements are designed to operate at (3.6 GHz) and are located on the corners of the smartphone PCB. The proposed MIMO antenna offers good S-parameters, high-gain radiation patterns, and sufficient total efficiencies, even though it is arranged on a high-loss FR-4 dielectric [17].

An end-fire phased array antenna has been presented, the element antenna has a leaf bow-tie shape and it serves the (28 GHz, 38 GHz) bands. Its S_11 is (-20 dB at 28 GHz and -30 dB at 38 GHz). The MIMO antenna has eight elements of leaf-shaped bow-tie antenna which form a linear phased array, in this paper (9-11 dBi)gain was achieved [18].

A compact MIMO antenna system has been presented, there are two antenna elements employed in the system, the first one has a rectangular shape and the second has a circular shape, the combination of these two antennas serves a group of frequencies (1.50 GHz,2.2 GHz and 28 GHz) [19].

A single-band PIFA antenna has been presented, it has three rectangular shape elements located at the same line and separated by an equal distance between their centers the antenna serves (28 GHz) frequency and its S_11 is (-25 dB) at this frequency, the peak gain of it is (6.06 dBi), this designed is served single band only and array structure has not be used, the proposed antenna design [20].

A 28 GHz mesh-grid antenna array is presented, the array offers a fan-beam-like radiation pattern with the main radiating structure composed of an array of vias within a 10-

layer FR4 PCB, the proposed array offers a -10 dB S_11 (bandwidth of > 3 GHz) with 3.5 dB single-element simulated gain with (> 10.9 dB) gain of a 16-element array [21].

A dual-band MIMO antenna a fairly low mutual coupling using a novel round patch EBG cell. with an antenna of (19.25×26×0.79 〖mm〗^3), they succeeded in obtaining a gain of (7.58 dB and 5.72 dB at 28 GHz and 38 GHz), respectively, radiation efficiencies of more than (86%) at both frequency bands were achieved [22].

A dual band MIMO antenna for 5G handsets has been presented, the operation frequencies are (2.6 GHZ and 3.6 GHz), the single element antenna has a suitable size for handsets and its S_11 shows about (-15 dB at 2.65 GHZ and 3.75 GHz). The MIMO antenna has 4 elements and its S_11 shows a deep value equal to (-80 dB at 2.8 GHz). [23].

A dual band antenna array with a circular polarization and beam steering capability features has been presented, its operation bands are 28 GHz and 38 GHz. The single element consists from three copper layers where the middle layer has T-shape feeding line every substrate layer has a hole for aperture feeding, these single elements used in a 12-element array for a mobile handset where they were divided equally on top, right and left sides of the mobile. However, the fabrication of this design in not easy compared with the proposed antenna design [24].

A compact millimeter wave massive MIMO has been presented, its S_11 is (-17 dB at 28 GHz and -28 dB at 38 GHz), at 28/38 GHz the gain value is more than (12 dBi) at each band, antenna elements are distributed in space for massive MIMO base station architecture with a radius of (25 mm), total beams scanning of 360° is achieved by 12 switched elements [25].

Rectangular patch antenna design

The rectangular patch is BY far the most widely USED configuration. It IS very easy to ANALYZE USING both transmission line AND cavity models, which are MOST accurate FOR THIN substrates [5][6]. For designing the patch antenna, rectangular micro-strip antennas are designed, made of a rectangular patch with dimensions width, (Wp), and length, (L), over a ground plane with its width (Wg), length (Lg), and substrate thickness (h) and dielectric constants (ε_r) of the dielectric material .To compute the parameters, the following are utilized [2]. The width of the MPA

$$W_p = \frac{v_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

Where $v_0 -$ *is the speed of signal*
$f_r -$ *is the resnance frequency*

The dielectric constant of effective potential:

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \quad (2)$$

The effective length:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (3)$$

Where c *speed of light*

The following is applied in order to eliminate the fringing effect, and as a result, the accurate length of the patch may be determined by: -

$$\Delta L = \frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

The performance of the rectangular patch antenna for different substrate heights was analyzed for the application of a 5G communication system, a micro-strip patch antenna consists of a conducting patch of any planar or non-planar geometry on one side of a dielectric substrate with a ground plane on another side, for design Rectangular patch antenna, will follow the design procedure presented in previous paragraph, first choose the substrate and determine the resonant frequencies and then calculate the antenna dimensions, based on the block diagram figure.1, the antenna design parameters with different dielectric substrate heights have been calculated and modelled, table (1).

Table 1: Design parameters for different substrate materials

Design parameters	Heights of the substrate **(mm)**			
	1..575	2.5	3.8	4
Patch width (mm)	15.06	15.06	15.06	15.06
Patch length (mm)	13.45	17.49	19.02	21.01
Ground width (mm)	19.47	25.48	36.78	40.06
Ground length (mm)	17.46	23.73	34.88	39.51

By the parameters tabulated in table (1), and the frequency of (28 GHz), single band antenna, a gap coupled feed line is used in the design to achieve matching with improvement in antenna bandwidth, figure .2 shows a single-element patch antenna without slots, as it was designed based on the different substrate heights, to achieve dual-band operation for the micro-strip patch antenna for 5G communication system, an L-Shaped slot has been made on the patch as shows in figure .3

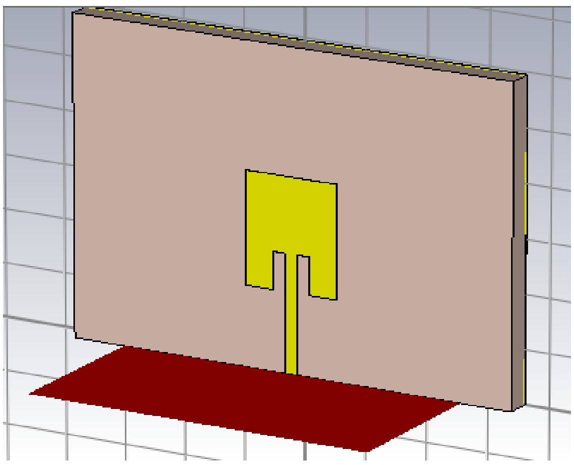

Figure 1: Single element antenna without slots

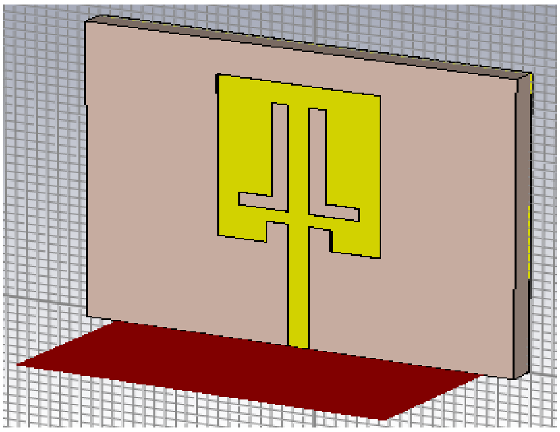

Figure 2: L-Shape slotted single element

Results and discussion

By using the parameters mentioned, it is possible to simulate S-parameters and even the three-dimensional directivity pattern of the single-element patch by CST MWS, the CST is a Microwave Studio is an electromagnetic simulation software for passive 3-dimensional structures based on the resolution of Maxwell's equations using the technique of finite integral equations (Finite Integration Technique). This numerical method offers a discretization of the space allowing the description directly in three dimensions of all the components of the systems described, which allows it to be applied to many electromagnetic problems ranging from static to microwaves in time and frequency analyzes [8], the simulation results for the (S_{11}) values, and the VSWR are shown in figure .4 to figure .7

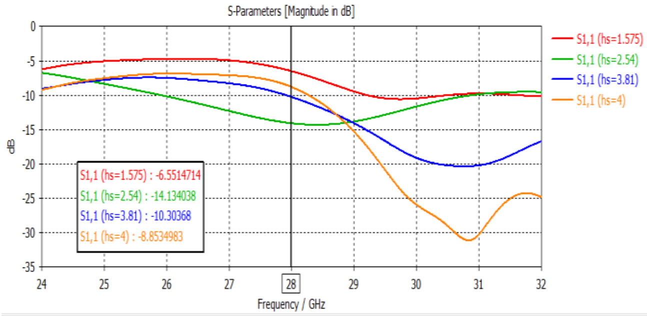

Figure 3: Single element antenna without slots simulation result (S_{11})

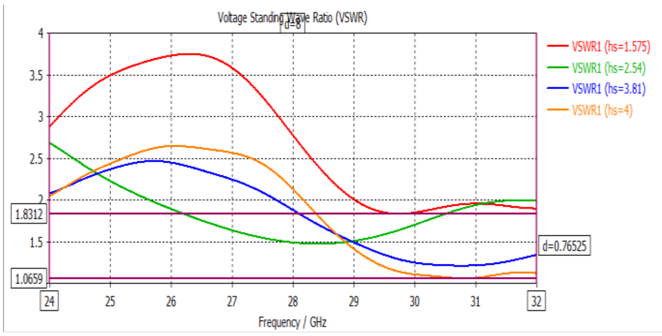

Figure 4: L-Slotted single element Simulation result (S_{11})

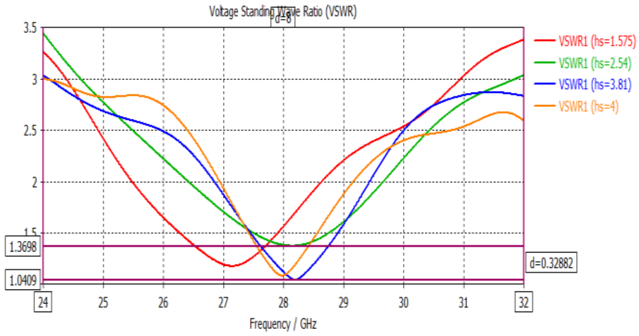

Figure 5: L-Slotted single element Simulation result (VSWR).

Figure .5, shows a simulation result of L-Shape slotted single element at the resonance frequency, as this design gives the best results compared to the without slots design, and is because the resonance occurs at the Required frequency, and at the magnitude of the (S_11) parameter is equal to (-27.8 dB at 28 GHz) with a large bandwidth of 10 dB ranging from (2 to 2.99 GHz), and the value of VSWR at the same frequency is equal to (1.1) as shown in figure .6.
The simulation results for all the antennas have been tabulated, table (2), presents the performance parameters of antennas for different heights of dielectric substrate materials.

Table 2: Fundamental parameters of the patch antenna in the 28 GHz frequency.

Design parameters	**Heights of the substrate (mm)**							
	1.575		2.54		3.81		**4**	
Resonance Frequency (GHz)	29.7	27.1	28.	28.1	30.7	28.2	**30.8**	**28**
S11(dB)	-10.6	-13	-14.4	-16	-20	-25	**-31**	**-27.8**
VSWR	1.8	1.17	1.5	1.37	1.2	1.04	**1.04**	**1.08**
Bandwidth (GHz)	1.3	2.9	2.2	2.99	< 0.5	2.4	< 0.5	**2.1**
Gain (dBi)	6.99	8.7	8.41	10.3	9.4	10.6	**10.4**	**10.9**
Directivity (D)dBi	7.74	9.5	11.5	9.21	10.5	11.7	**11.5**	**12.1**
Efficiency	≅ 91.2%		≅ 90.9%		≅91.6%		≅ 91.7%	

The antennas radiation pattern has an appropriate shape as shown in the figures .7 d, and figures .8 d, because the radiation is concentrated in the upper part of the antenna, of course this is what it should be normally for this type of antennas, it increasing the height of the dielectric substrate is advantageous in increasing the bandwidth of micro-strip antenna, which is desirable in compact antenna application. however, increasing height of the dielectric substrate also results in expansion of the size of antenna, increased return loss and VSWR. but substrate with greater height can be used to achieve better directivity.

Conclusion

A set of designs of effective microstrip antennas for 5G communication systems has been proposed using substrate materials with different thickness (mm). key para-meters (such as return loss, radiation patterns, directivity, and bandwidth), affect the design and applications. The simulation results prove that the antenna performance meets the requirements of 5G communication systems, and that the single element antenna has the reflection coefficient (S_11) of (-26 dB), less than -10 dB in the frequency range of (26.1 – 27.8 GHz). Single antenna and array antenna fed from a single port have a maximum gain of (10.9dB) and a bandwidth of 10dB.

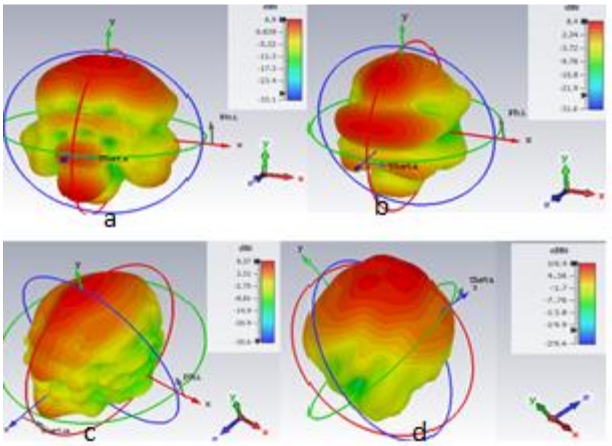

Figure 6: non-slotted antenna radiation pattern (Realized Gain)

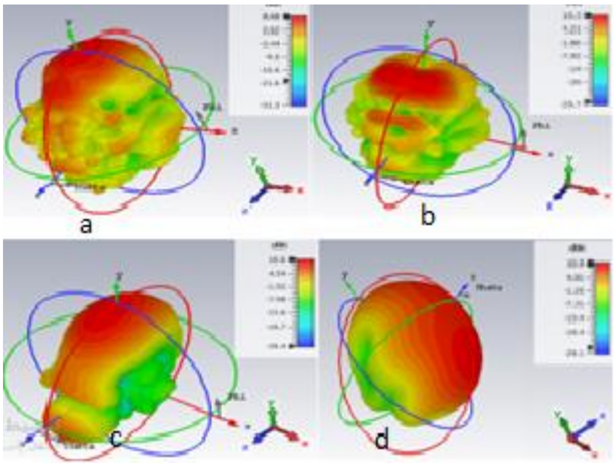

Figure 7: L-Slotted antenna radiation pattern at 28 GHz (Realized Gain)

Author Contributions: "Conceptualization, Name, Name and Name; methodology, Name, and Name; writing—original draft preparation, review and editing, Name, Name, and Name. All authors have read and agreed to the published version of the manuscript."

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