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Design of a UWB Coplanar Antenna with Step Graded Ground Plane for 5G and Modern Wireless Communication Applications

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This article covers a wideband coplanar rectangular patch antenna for 5G and wireless communication applications below 6 GHz. The proposed antenna design comprises of a rectangular CPW fed patch with a partial ground plane loaded with stair-case shaped slots. The simulated results demonstrate that the studied antenna has working band that ranges from 3 GHz to 6 GHz with $|S_{11}| \leq 10$ dB, covering the whole N77/N78/N79 band for 5G sub-6 GHz as well as several modern wireless communication systems including WiMAX, WLAN and long-term evolution (LTE). In addition, the various procedures can be utilized to design and match this antenna for additional frequency bands. The examined antenna displays steady bidirectional radiation patterns, high gain, and efficiency. The projected structure has an overall size of 31.84 × 26.06 mm² and it is designed with a cheap FR4 type substrate of 4.4 relative dielectric constant. The suggested antenna has a miniaturized dimensions and good electrical performances. The proposed antenna is developed and simulated using Computer Simulation Advanced Design System (ADS). It is of potential interests because of its symmetrical radiation behavior, tiny footprint, and planar form. The investigated antenna may be a prospective choice for usage in 5G for sub 6 GHz bands and current wireless communication systems due to its superior performance parameters.

Keywords: Microstrip Antenna, CPW, Ground plane, 5G technologies, Wideband, Wireless applications.

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1. INTRODUCTION

Wireless communication systems have developed considerably over the last two decades. These systems are evolving at the same pace as the technological advances achieved in all sectors and are expected to continue to grow in the coming years [1, 2]. The enormous progress of wireless communication techniques leads to the requirements of advanced antenna designs as a part of systems. Antenna downsizing is crucial for the best design of integrated systems for mobile and wireless communication since it is a crucial component in this sort of communication [3]. The planned antenna must have numerous resonant techniques to cover the entire 5G spectrum below 6 GHz in order to provide the quickest 5G services. Therefore, an antenna with broadband operation with complete coverage of entire performance 5G bands below 6 GHz as well as other application bands is therefore extremely desirable. A preferred 5G antenna should be small, efficient and compatible with wireless technology. In this prospect, a low-profile planar antenna is highly recommended for straightforward integration into wireless devices. A planar antenna for 5G applications has already been designed using a variety of approaches and technologies [4-6]. Due of its benefits, the coplanar patch antenna is one of the most used antenna shapes in wireless communication systems due to its cheap cost and easiness in integration. To overcome several intrinsic limitations of this type of antenna (such as: limited bandwidth, low gain and degradation of radiation efficiency at high frequencies), a new technique, based on the photonic bandgap concept, can be used. Photonic bandgap materials, also known as electromagnetic bandgap materials (EBG), have attracted a lot of interest since their creation by Professor Eli Yablonovitch, at the end of the eighties. He introduced a band gap to control the stimulated and spontaneous emission of light [7]. These materials have interesting physical properties (in terms of propagation) for electromagnetic waves in both the optical and microwave fields, but more particularly in the fields of antenna [8-14]. There have already been several different antennas suggested for use in 5G communication applications. For example, in ref. [15] the authors have explored a planar antenna for a 5G mobile terminal operating at less than 6 GHz. Impedance bandwidths at a reference level of – 6 dB from 0.7-0.96 GHz and 1.6-5.5 GHz are reported but it requires an extensive ground plane of 135 × 80 mm². For the medium bands LTE-R and 5G, an ellipse-shaped patch antenna has been presented in [2]. The planned antenna's total size of 180 × 60 mm² allowed it to function in two distinct bands from 0.66 to 0.79 GHz and 3.28 to 3.78 GHz. For 5G communication applications, [16] presents a dual-polarized magnetoelectric dipole antenna. It has four horizontal fishtail patches, four vertical patches, and four horizontal patches. The antenna reports an overall dimension of

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150 × 150 mm², covering a frequency range of 3.05 to 4.42 GHz. But the N79 band is not covered (4.4-5.0 GHz). Furthermore, the 3D profile of the device restricts its use in portable communication devices [17-19]. This work presents the design and studies of a coplanar rectangular patch antenna with staircase shaped partial ground structure. It prescribed design is intended for sub-6GHz 5G band and other wireless applications such as Wi-MAX, and WLAN.

2. RECTANGULAR PATCH ANTENNA DESIGN

The starting point of this study begins with the design of a rectangular patch antenna in narrow band microstrip technology that resonates at around 3.5 GHz. In this part, we will deal with the different design steps followed for the validation of the basic element which is mounted on a cheap FR4-style substrate with a 4.4 relative dielectric constant, 0.025 tangential losses, and 1.6 mm in thickness. To determine the dimensions of the rectangular patch antenna (Figure 1) that meets the chosen specifications, we have based on the analytical equations that model the rectangular patch antenna and this has allowed us to have the following dimensions, length: $L = 19.4$ mm and width: $W = 26.06$ mm.

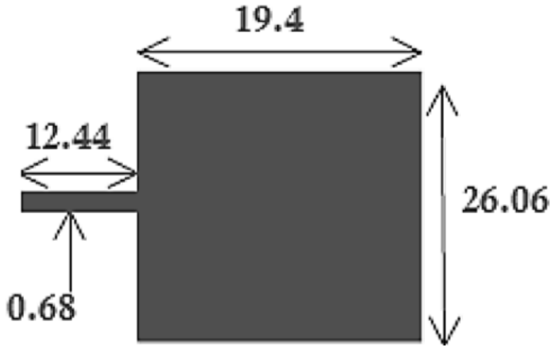

Fig. 1 – Final dimensions of the patch element

Once the dimensions of the patch antenna are determined, the simulation studies have been launched on the ADS software "Advanced Design System". The simulation of this antenna allowed to determine the design of the quarter-wave transformer allowing to adapt the antenna to its operating frequency. Using Linecalc which is a calculation software integrated in ADS and which allows to link the physical dimensions to the electrical dimensions (the electrical length and the input impedance). The dimensions quarter-wave feeder of the patch antenna is calculated after tuning of the antenna's length to center the frequency at around 3.5 GHz. The basic patch is appropriate for 3.5 GHz resonance frequency with a reflection coefficient below −10dB and a bandwidth equal to 71 MHz which is a very narrow band as shown in Fig. 2.

3. DESIGN OF THE WIDE BAND (WB) PATCH ANTENNA IN COPLANAR TECHNOLOGY FOR 5G

In this section, we discuss the suggested modifications in the geometry of the patch in order to convert it into wideband antenna to meets the requirements of sub 6 GHz bands for 5 G applications. After the validation of the basic radiating element which has a narrow bandwidth, the objective now is to keep

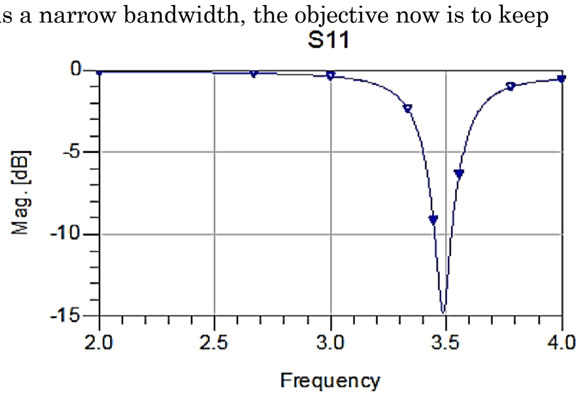

Fig. 2 – Reflection coefficient versus frequency

the same dimensions of the basic antenna and to switch to the coplanar technology which has the particular features of simple geometry, compact size and it makes the antenna easy to integrate with other electronic components. To increase the bandwidth, we worked on the optimization of the ground plane in the form of a staircase which is a technique. After a parametric study on the shape, the dimensions of the step graded slots in the partial ground plane are finalized. The modified shape of the suggested ground plane is depicted in Fig. 3. Table 1 illustrates the dimensions of prescribed ground plane geometry.

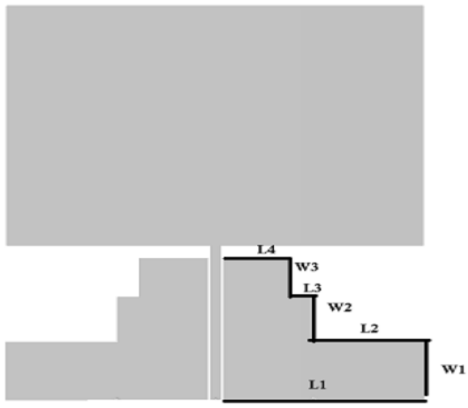

Fig. 3 – The proposed ULB antenna structure

Table 1 – Geometrical parameters of ground plane

Parameters	Unit (mm)
L_1	13.09
W_1	4.69
L_2	6.94
W_2	3.64
L_3	1.94
W_3	3.1
L_4	4.26
Gap	0.15

The reflection coefficients (S_{11}) are investigated for different geometries of the antenna ground plane as shown in Fig. 4. The designed antenna has a wide bandwidth (WB) of 3 GHz at – 10 dB reference S_{11} level for the case of suggested ground structure. The 3D radiation pattern is shown in Fig. 5. It shows bidirectional shape.

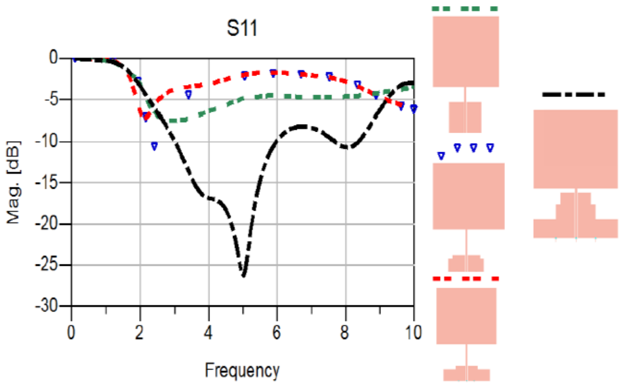

Fig. 4 – S_{11} parameter vs frequency response

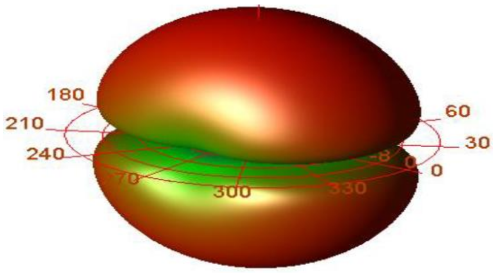

Fig. 5 – 3D radiation pattern

The Comparison between the proposed antenna structure and the literature is shown in the Table 2. The suggested antenna is modest in size, has a bidirectional radiation pattern, and has a low gain compared to other structures because of the CPW ground, but it has a gain that is acceptable for the intended applications.

Table 2 – A comparison between the proposed antenna and earlier works

Ref.	Operational Frequencies (GHz)	S_{11} Parameter (dB)	Dimensions (mm^2)	Gain (dBi)
[18]	2.4 and 3.5	– 14 / – 25	1862	1.94
[19]	2.5 and 6	– 14 / – 22	1120	2.6
[20]	(2.8-3.6) and (6.5-6.7)	– 15 / – 16	1050	1.31/1
This work	3.5 and 5	– 15 / – 26	806	1.2/2.4

4. CONCLUSION

The wideband coplanar rectangular patch antenna is designed and studied for sub 6 GHz 5G and other modern wireless communication applications in the Microwave S and C bands. The effects of various suggested ground plane structures are studied and discussed. The proposed ground plane shape of the antenna has been retained by launching the step graded stair case slots in order to achieve wideband resonance response. Moreover, the suggested antenna is well miniaturized and provides significant bandwidth of 3000 MHz from 3 to 6 GHz wide frequency span covering the intended 5G, WLAN and Wi-MAX wireless applications.

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Конструкція UWB копланарної антени зі ступінчастою площиною заземлення для 5G і сучасних додатків бездротового зв'язку

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У цій статті розглядається широкосмугова компланарна прямокутна патч-антена для 5G і програм бездротового зв'язку нижче 6 ГГц. Запропонована конструкція антени складається з прямокутного патча з живленням CPW з частковою площиною заземлення, завантаженою прорізами у формі сходів. Змодельовані результати демонструють, що досліджувана антена має робочий діапазон у діапазоні від 3 ГГц до 6 ГГц із |S11| ≤ 10 дБ, що охоплює весь діапазон N77/N78/N79 для 5G нижче 6 ГГц, а також кілька сучасних систем бездротового зв'язку, включаючи WiMAX, WLAN і довгострокову еволюцію (LTE). Крім того, різні процедури можуть бути використані для розробки та узгодження цієї антени для додаткових діапазонів частот. Досліджувана антена має стійку двонаправлену спрямованість випромінювання, високе посилення та ефективність. Проектована структура має загальний розмір 31,84 × 26,06 мм² і розроблена з дешевою підкладкою типу FR4 з відносною діелектричною проникністю 4,4. Запропонована антена має мініатюрні розміри та хороші електричні характеристики. Запропонована антена розроблена та змодельована за допомогою системи вдосконаленого проектування комп'ютерного моделювання (ADS). Він представляє потенційний інтерес через його симетричну поведінку випромінювання, крихітний слід і плоску форму. Досліджувана антена може бути перспективним вибором для використання в 5G для діапазонів нижче 6 ГГц і сучасних системах бездротового зв'язку через її чудові параметри продуктивності.

Ключові слова: Мікросмугова антена, CPW, Наземна площина, Технології 5G, Широкосмуговий зв'язок, Бездротові програми.