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REGULAR ARTICLE

Design and Development of Compact High Bandwidth Microstrip Patch Antenna for Wireless Communication

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In this study, a dipole low-profile, high bandwidth compact Microstrip Patch Antenna (MPA) consisting of slot loaded ground and a standard rectangular patch is introduced for 5G applications. Ground plane of conventional dipole MPA has been modified by incorporating two identical slots at optimum position. These slots lengthen the current path and hence lower resonance frequency as well as compact structure is achieved. Presented MPA attains a high bandwidth of 0.44 GHz (2.16 – 2.6 GHz) with fractional bandwidth of 18.48% resonating at 2.2 GHz. The proposed MPA is configured on 1.542 mm-thick Rogers RO473G3 dielectric substrate, featuring loss tangent of 0.0022 and relative permittivity of 3. Improved impedance matching and bandwidth are provided by the slotted ground plane. Within achieved frequency range, the suggested antenna's peak gain ranges from 2.7 dBi to 3.2 dBi, with a maximum radiation efficiency of around 90%. Also isolation between co-pol and cross-pol component in radiation pattern is also attained for the presented antenna. The suggested antenna has a symmetric radiation pattern, is small and lightweight, has a steady gain, and would work well with wireless system equipment. The proposed antenna requires 89.29% compact compare to conventional antenna. The suggested antenna can be considered suitable for NR n77, n78 5G communication applications, part of C band wireless application due to its highly compact structure, high radiation efficiency and acceptable radiation pattern. Suggested antenna is developed, optimized with Computer Simulation Technology's (CST) Microwave Studio Suite software.

Keywords: Compact, High bandwidth, Rogers RO473G3, Wireless communication.

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1. INTRODUCTION

A future technological revolution to fulfill the growing demands for high-speed connections and Internet of Things (IoT) applications is evident from the considerable research being done on fifth generation (5G) technology. The Third Generation Partnership Project (3GPP) allows researchers to further extend their goals and advance the industry by regularly updating 5G technological standards. In addition to smartphones, numerous IoT devices will enable 5G technology to deliver a variety of services including smart buildings and cities, among other uses. A 5G antenna with a consistent radiation pattern, low latency, and low path loss is therefore crucial. In [1-2], S. Kumar et al. and M.U. Khan et al. evaluate the latest research on the different antenna layouts and how they might increase performance for 5G technologies. Furthermore, a comparison of several antenna designs follows a full discussion of 5G needs and antenna categorization. They have also attempted to look at several types of 5G antenna designs from an integrated standpoint, as well as their performance enhancement techniques, comparisons, and possible developments. In [3], A. Roy et al. proposed a compact broadband MPA for multi frequency wireless applications. Meandered slots are appropriately placed on the bottom and top plane of the Rectangular MPA to produce broadband characteristics. MPAs for 5G communication were introduced in a paper by P. Teresa and G. Umamaheswari in [4]. They demonstrate three different kinds of MPAs with various slot designs. Slot layouts decrease the effective area while increasing bandwidth. In comparison to the current design, the bandwidth is improved by adding additional slots to the arrangement. T. Tewary and colleagues provide a microstrip line fed "S" and "Heart" shaped wide band MPA in [5–6]. For 5G wireless communications, this is achieved by slots inserting in ground plane and radiating patch of the reference structure that are the right size and placed in the right places. T. Tewary et al. described miniature broadband planar antenna in [7-8] for a number of modern short- and long-range wireless communication applications, such as 5G communications at 3.5 GHz. The proposed radiating patch is constructed by transforming the upper side of a conventional rectangular patch into a semi-circular shape and the lower side into a shape resembling a staircase. In [9], C. H.L. Thi et al. offer a compact broadband dual-

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polarized antenna that may be used below 6 GHz for 5G applications. The magneto-electric (ME) dipole antenna that is being shown receives broadband dual-polarized radiation using an aperture-coupled feed made up of two orthogonally orientated microstrip lines that are linked to four shorted patches via a crossing slot. The electric and magnetic dipole modes are produced utilizing spaces between the patches and the shorted patches, respectively. A small, low-profile MPA for 5G applications is presented by L. C. Paul et al. in [10]. It uses slotted rectangular parasitic element along with slot loaded partial circular ground plane. Additionally, different low-profile patch antennas with different patch sizes and shapes have been created for 5G communications [11–16]. For microstrip patch antennas, the work in [17] suggests a compact antenna design method and a double-layered defective ground structure (DGS) arrangement. In [18], a tiny antenna for 5G applications is built and analyzed using complementary split-ring resonator (CSRR) metamaterials. A multiband antenna for quad-band applications that is powered by a tiny, coplanar waveguide (CPW) is developed and analyzed in the work presented in [19]. The idea with three symmetric slots is to make them seem like Christmas trees. Because of slots of different widths to lengthen the current carrying route, the proposed antenna resonates at the required frequency ranges.

In this proposed work, a microstrip line fed rectangular MPA having ground plane embedded with slots is discussed. Presented MPA has consistent gain and efficiency over a wide bandwidth of 0.44 GHz (2.16 – 2.6 GHz). To enhance impedance matching and for achieving compact antenna configuration, surface current path length is increased by incorporating slots on the ground plane to obtain lowest operating frequency. Due to compact structure, broadband characteristics, high efficiency, acceptable gain and consistent radiation pattern, presented MPA is suitable for n77, n78 5G wireless communication application.

2. REFERENCE AND PROPOSED ANTENNA

The original reference antenna design was primarily for Wi-Fi 6E devices operating in the standard 6 GHz frequency band. A 1.542 mm thick Rogers RO473G3 substrate with a relative dielectric constant (ε_r) of 3 is used for the antenna that is being described. Therefore, using the standard equation [20] (1), where c represents the velocity of light, the width of the patch (W_P) at a resonant frequency (f_r) of 6 GHz can be determined using the Eq. (1)

$$W_P = \frac{c*\sqrt{2}}{2*f_r*\sqrt{1+\varepsilon_r}}; \qquad (1)$$

Eq. (2) is used to get the patch's effective dielectric constant.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} * \left[1 + 12 * \frac{h}{W_P}\right]^{-\frac{1}{2}} \qquad (2)$$

Eq. (3) determines the patch's extended incremental length, ΔL.

$$\Delta L = 0.412 * h * \frac{(\varepsilon_{reff}+0.3)*(\frac{W_P}{h}+0.264)}{(\varepsilon_{reff}-0.258)*(\frac{W_P}{h}+0.8)} \qquad (3)$$

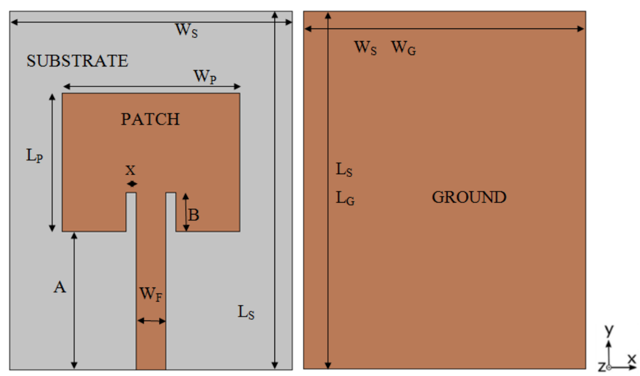
Eq. (4) determines the patch's actual length.

$$L = \frac{c}{2*f_r*\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (4)$$

And the effective length is given by (5)

$$L_{eff} = L + 2\Delta L \qquad (5)$$

The dimensions of the radiator corresponding to a resonant frequency (f_r) of 6 GHz are 17.678 mm (W_P) and 13.728 mm (L_P), respectively. The initial reference antenna's radiating patch and ground plane layout, as well as its measurements (mm), are depicted in Fig. 1. First, a 28 mm × 35.6 mm × 1.542 mm substrate is used as a reference. A radiating patch in the shape of a rectangle is created on top of the substrate.



a b

Fig. 1 – Reference MPA, (a) top surface(radiating patch) (b) bottom surface (ground)

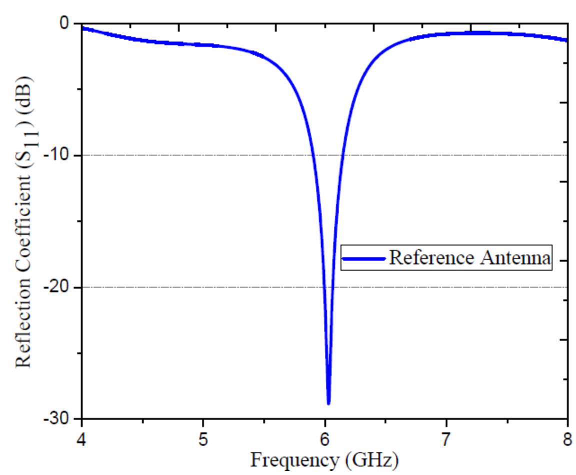


Fig. 2 – Reflection Coefficient (S_{11}) of Reference antenna

Fig. 2 illustrates reflection coefficient of the reference antenna which resonates at 6.06 GHz. Fig. 3 shows proposed antenna configuration. Only ground plane has been modified by incorporating two similar slots. These slots lengthen the current path and hence lower resonance frequency is achieved. Table 1 tabulates all the dimensions of the antenna design parameters.

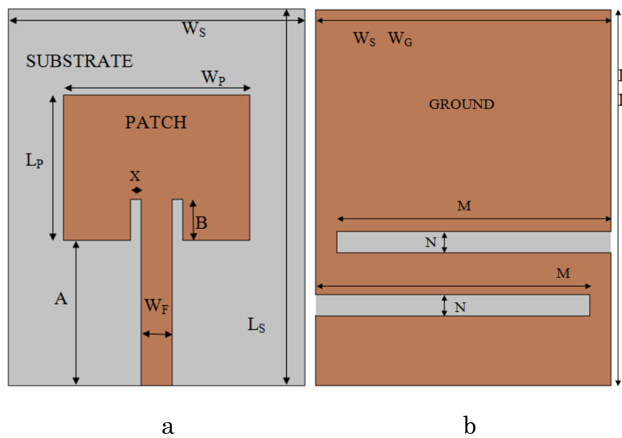


Fig. 3 – Proposed MPA, (a) top surface(radiating patch) (b) bottom surface (ground)

Table 1 – Optimum Design Parameters and Dimensions in mm

Parameter	Dimension	Parameter	Dimension
L_S, L_G	35.6	A	13.728
W_S, W_G	28	B	3.864
W_F	3	M	26
L_P	13.728	N	2
W_P	17.678	X	1

3. ANTENA RESULTS AND DISCUSSIONS

The CST MWS software is used to perform all of the simulation results. The suggested antenna's simulated reflection coefficient is displayed in Fig. 4. It is also evident from the simulation findings in Figs 2 and 4 that the suggested MPA resonates at 2.2 GHz whereas the reference antenna resonates at 6.06 GHz. Thus, the suggested antenna is smaller than conventional one. The suggested antenna exhibits an impedance bandwidth of 0.44 GHz (2.16 – 2.60 GHz) with a fractional bandwidth of 18.48%, whereas the reference antenna displays an impedance bandwidth of 0.47 GHz (5.9 – 6.2 GHz) with a fractional bandwidth of 4.95%.

Fractional bandwidth has been calculated from the obtained result.

$$\%\ \text{Bandwidth} = \left(\frac{(F_{HH} - F_{LL})}{F_{CC}} \times 100\right)\%$$

Where, F_{HH} – High level frequency; F_{LL} – Low level frequency; F_{CC} – Central level frequency $F_{CC} = (F_{HH} + F_{LL})/2$

The compactness is computed using the following relation

$$compactness(\%) = \left(\frac{Area_1 - Area_2}{Area_1}\right) \times 100\%$$

Where $Area_1$ is the patch area of the ideal MPA at 6 GHz and $Area_2$ is the patch area of the proposed MPA at 2.2 GHz.

Width and length of the rectangular patch antenna for 2.2 GHz resonant frequency applying the equation 1-5 can be found as 53 mm and 42.79 mm.

So the *compactness* can be calculated as:

$$compactness(\%) = \left(\frac{(2267.87 - 242.68)}{2267.87}\right) \times 100\% = 89.29\%$$

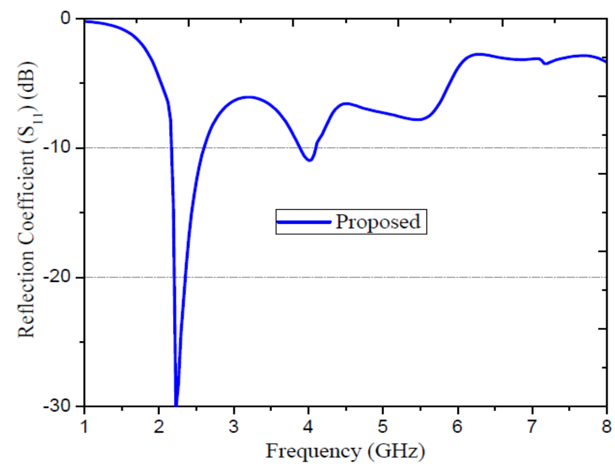


Fig. 4 – Reflection Coefficient for proposed antenna

The efficiency and peak gain (dBi) of the suggested antenna are shown in Fig. 5. Efficiency is 90% and max gain is 3.2 dBi at 2.2 GHz, both of which are acceptable.

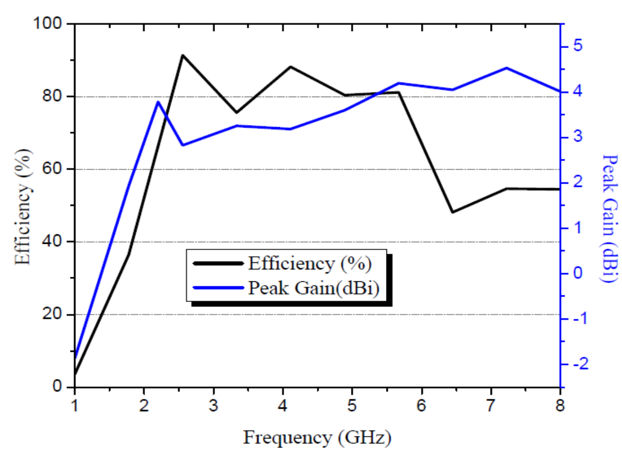


Fig. 5 – Efficiency (%) and peak gain of proposed antenna

The antenna's normalized simulated radiation pattern is displayed in Figs. 6 and 7 for the *E* and *H* planes at 2.2 GHz resonant frequency. Co-pol is greater than cross-pol in all the directions with sufficient separation in *H* plane where as in *E* plane also Co-pol is greater than Cross-pol in maximum direction. In terms of overall antenna size and % bandwidth comparison of the suggested antenna with similar types of mentioned literature, it is evident that the suggested antenna is significantly smaller overall than the others [10-15]. Even though several works attain high bandwidth percentages [10, 13, 14], their overall dimensions are at least 70% higher.

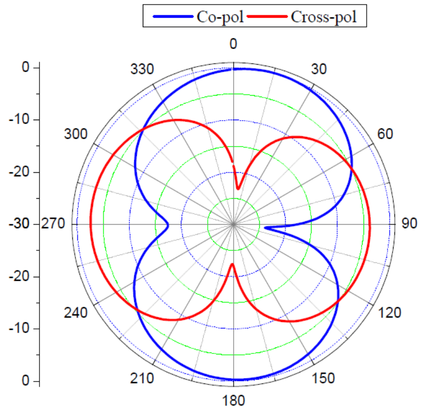


Fig. 6 – Radiation Pattern (*E* plane) at 2.2 GHz

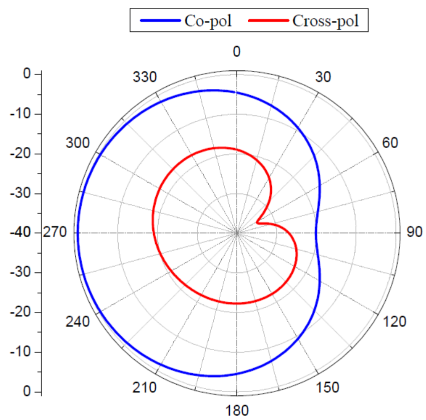


Fig. 7 – Radiation Pattern (*H* plane) at 2.2 GHz

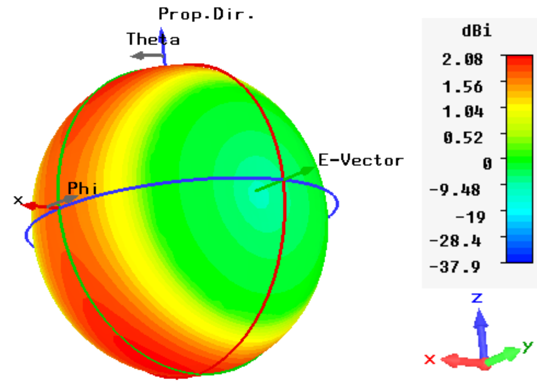


Fig. 8 – 3D polar gain plots at 2.2 GHz

4. CONCLUSION

For wireless communication applications, a low-profile, compact high bandwidth MPA with slot-loaded ground plane is presented in this paper. The presented MPA shows high bandwidth characteristics (2.16 to 2.6 GHz) with 18.48% percentage bandwidth. Patch area compactness of 89.29% is attained for proposed MPA. Throughout the entire operating band, it exhibits consistent gain, high efficiency and consistent radiation pattern having enough isolation between co-pol and cross-pol component. Slotted ground is utilized to achieve compact structure and better impedance matching. The suggested antenna can be considered for NR n77, n78 5G communication applications, part of C band wireless application like internet access, disaster recovery in remote areas, television broadcasting etc.

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Проектування та розробка компактної мікросмужкової патч-антени з високою пропускною здатністю для бездротового зв'язку

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У цьому дослідженні представлено низькопрофільну компактну мікросмужкову патч-антену (MPA) з високою пропускною здатністю для застосувань 5G, що складається з щілинного заземлення та стандартного прямокутного патча. Заземлювальна площина звичайної дипольної MPA була модифікована шляхом додавання двох однакових пазів в оптимальному положенні. Ці пази подовжують шлях струму, і, отже, досягається нижча резонансна частота, а також компактна структура. Представлена MPA досягає високої пропускної здатності 0,44 ГГц (2,16 – 2,6 ГГц) з частковою пропускною здатністю 18,48%, що резонує на частоті 2,2 ГГц. Запропонована MPA налаштована на діелектричній підкладці Rogers RO473G3 товщиною 1,542 мм, що характеризується тангенсом кута втрат 0,0022 та відносною діелектричною проникністю 3. Покращене узгодження імпедансу та пропускна здатність забезпечуються щілинною заземлювальною площиною. У досягнутому діапазоні частот піковий коефіцієнт посилення запропонованої антени коливається від 2,7 дБі до 3,2 дБі, з максимальною ефективністю випромінювання близько 90%. Також для представленої антени досягнуто ізоляції між копольною та крос-польною складовими в діаграмі спрямованості. Запропонована антена має симетричну діаграму спрямованості, є невеликою та легкою, має стабільний коефіцієнт посилення та добре працюватиме з обладнанням бездротових систем. Запропонована антена вимагає компактності 89,29% порівняно зі звичайною антеною. Запропоновану антену можна вважати придатною для застосування в зв'язку NR n77, n78 5G, частини бездротового застосування в діапазоні C завдяки її дуже компактній структурі, високій ефективності випромінювання та прийнятній діаграмі спрямованості. Запропонована антена розроблена та оптимізована за допомогою програмного забезпечення Computer Simulation Technology (CST) Microwave Studio Suite.

Ключові слова: Компактний, Високошвидкісний, Rogers RO473G3, Бездротовий зв'язок.