A II-shaped slotted patch antenna with a partial ground structure for lower 5G/WiFi/WiMAX applications

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A B S T R A C T

In this research work, a II-shaped slotted microstrip patch antenna (MPA) with a partial ground structure for lower fifth generation (5G)/wireless fidelity (WiFi)/worldwide interoperability for microwave access (WiMAX) applications is presented. The proposed MPA is optimized and designed by using the computer simulation technology (CST) microwave studio (MWS) suite version of 2018. The II-shaped slotted MPA is mounted on low loss dielectric material Rogers RT5880 with a height of 0.79 mm and relative permittivity of 2.2. The length (L) and the width (W) of the II-shaped antenna are 35 mm and 31 mm respectively, which covers the operating frequency range 2.87–5.47 GHz. The MPA has a wide impedance bandwidth (2600 MHz), high radiation efficiency (90.88%), acceptable gain (2.647 dB) and low return loss (simulated: -36.81, measured: -25 dB). The VSWR over the entire operating frequency is regarded as 1 < voltage standing wave ratio (VSWR) < 2 and VSWR is 1.0293 at centre frequency 3.47 GHz. The current distribution on the surface as well as the input impedance of the II-shaped slotted MPA are also favorable. The MPA shows an omni-directional property over the entire operating frequency band. Since the time domain, frequency domain and fabricated results are buttressed by each other, the designed II-slotted MPA is one of the best candidates for high speed lower 5G/WiFi/WiMAX communication applications.

1. Introduction

Over the last few decades, the 5G mobile communication system has become much more efficient and increased their demand due to their significant advantages such as low latency, high data rate, and high data capacity [1]. Moreover, 5G has a great impact on the application of high data speed, wide bandwidth, and stable gain, which are already being used in several countries. The different 5G spectrum, and corresponding frequency bands for different countries are shown in Table 1 [2].

With the continuous deployment of cellular and mobile communication technology, mobile communication generation is going on 5G technology due to users demand. After adding internet of things (IoT), the main aim of the future 5G research is to enhance the spectrum related issues, seamless wide-coverage area (100 Mbps user experienced data rate) and super high density control [3, 4]. Microstrip patch antenna for lower 5G/WiFi/WiMAX applications is widely used due to having a suitable compact size and omnidirectional radiation pattern. Moreover, microstrip patch antennas are considered as highly efficient for sustaining huge bandwidth, stable gain and high efficiency [5]. Recently, Researchers are keen to work in low loss dielectric substrates like Rogers RT/Duroid 5880 because it is suitable to obtain wide bandwidth, stable gain and good radiation patterns [6]. In [7], a monopole microstrip patch antenna with dimensions of $40 \times 20 \text{ mm}^2$ is proposed for WLAN/WiMAX applications, and the corresponding antenna has dual operating bands (3.5 GHz and 5.2 GHz). At the 1st band of 3.5 GHz, the gain and the radiation efficiency of 2.6 dB and 90% respectively. A. Azim et al [8] designed and fabricated a multi-slotted MPA for LTE and Sub-6 GHz communication. A 20 $\times$ 30 $\times$ 1.5 mm$^3$ FR4 substrate (4.3, 0.02) is used. The corresponding antenna covers the operating frequency (3.15–5.55 GHz), the radiation efficiency differs (68.4–79.6) and it’s a planar profile antenna. The author in [9] reported a wideband slotted compact MPA for 6 GHz applications. They used a partial ground technique for achieving wide bandwidth and the simulation was conducted by HFSS. The antenna operates at centre frequency of 3.65 GHz, the gain is $\approx 2.5$ dB and the obtained bandwidth is 700 MHz. A low-profile microstrip antenna with stable radiation pattern in a relatively wide band is...
presented for 5G applications [10]. The antenna has a bandwidth from 2.84 to 5.17 GHz, peak gain 6.3 dBi and average efficiency of 64%. In [11], a planar ultra-wideband antenna is proposed for WiMAX and WLAN applications. With a dimension of $30 \times 22 \times 1.6$ mm$^3$, the corresponding microstrip patch antenna operates from 2.98 - 12 GHz with an average gain of 3.95 dBi, and the VSWR is less than 2. In [12], a triple slotted patch antenna is introduced. The antenna has a higher area of 30.2 mm$^2$. They used lossy FR4 dielectric material, having the centre frequency of 3.5 GHz, the simulated results were VSWR of 1.05, gain of 5 dB and an efficiency of 95%. I. Ishhteyaq et al. [13] designed and fabricated a rectangular slotted antenna for Sub-6 GHz applications. The resonant frequencies are 3.3 GHz and 4.5 GHz and bandwidths are 0.34 GHz and 0.9 GHz. In [14], A microstrip patch antenna with T-structured is composed of 22 × 24 mm$^2$ of Rogers RT 5880 LZ (ɛr = 2) that works at centre frequency of 3.6 GHz. It showed gain and efficiency of 2.52 dB and 98.47%, respectively, at centre frequency of 3.6 GHz. In [15], a microstrip patch antenna is introduced by using FR4 substrate material with dielectric constant and thickness of 4.4 and 1.5 mm, respectively. The antenna exhibits the operating frequency of 3.1-4.2 GHz.

The main objective of this work is to lessen the MPA size and obtain high performance including stable gain and high efficiency. Here, the total volume of the proposed II-slotted MPA is $35 \times 31 \times 0.79$ mm$^3$, which is applicable for lower 5G (3.3 GHz–4.2 GHz)/WiFi-5 (5.15 GHz–5.85 GHz)/WiMAX rel 2 (3.4-3.6 GHz) communication systems.

2. II-shaped slotted antenna

At first, the π-shaped slotted antenna is designed and simulated by both time domain (TD) and frequency domain (FD) solvers of a professional 3D EM software: CST-MWS v. 2018. Rogers RT 5880 is used as a substrate with a height of 0.79 mm ($\varepsilon_r = 2.2, \tan(\delta) = 0.0009$). The ground plane is etched on copper (annealed) with a thickness of 0.035 mm. The proposed π-shaped slotted MPA, consists of a triangular patch with a π-slot, four parallel bars and a 50 Ω feedline, which is illustrated in Figure 1(a), as a fabricated prototype view of the π-slotted MPA with a partial ground. Initially, the size of the antenna has been estimated by using some fundamental Eqs. (1), (2), (3), and (4) then the greatness of the MPA is optimized to $35 \times 31 \times 0.79$ mm$^3$ by using CST-MWS [6].

**Table 1. 5G frequency spectrum.**

| Region       | Frequency range                     |
|--------------|------------------------------------|
| Europe       | 3400MHz–3800MHz (awarding trial licenses). |
| China        | 3300MHz–3600MHz (ongoing trial), 4400MHz–4500MHz and 4800–4990MHz. |
| Japan        | 3600MHz–4200MHz and 4400MHz–4900MHz. |
| Korea        | 3400MHz–3700MHz.                     |
| USA          | 3100MHz–3550MHz and 3700MHz–4200MHz. |
| India        | 3300MHz and 3400 MHz.                |
| Ireland      | 3400MHz–3800MHz.                     |
| Italy        | 3550MHz and 3700MHz.                 |
| Spain        | 3600MHz–3800MHz.                     |

Effective length, $L_{\text{eff}} = \frac{c}{2 f_r \sqrt{\varepsilon_r}}$ (3)

And

Patch length, $L_p = L_{\text{eff}} - 2\Delta L$ (4)

The metallic patch of the π-slotted 5G antenna including labeling is represented in Figure 1(b). Substrate length ($L$) is taken as 35 mm. Substrate is designed to have a width ($W$) of 31 mm. From the front view, there is an isosceles triangular patch which has the lengths of base ($A$) and leg ($C$) are 26 mm and 15.26 mm, respectively. The length of the parallel bars are 22 mm, 17 mm, 13 mm and 8 mm which are denoted by $J, I, S$ and $G$, respectively and the width of parallel bars are 1 mm, 1.5 mm.
and 4.12 mm which are indicated by D, E and F, respectively. The length of the feedline ($L_f$) is 19 mm and width of the feedline ($W_f$) is 2.4 mm which ensures 50 $\Omega$ impedance matching. From the $\pi$-shaped slot as shown in Figure 1(c), the dimension of the $\pi$-slot on the isosceles triangular patch is \(x \times y = 6 \times 1 \text{ mm}^2\) and \(z \times y = 3 \times 1 \text{ mm}^2\). The dimension of $\pi$-slot is obtained by trial and error analysis. The impact of the $\pi$-slot is studied in the following results and parametric investigation section. In Figure 1(d), the area of the ground layer is 18.2 \(\times 31 \text{ mm}^2\) which is located at the bottom side of the Roger RT 5880 and thickness of the metal is 0.035 mm. Major design parameters of $\pi$-shaped slotted antenna are listed in Table 2. A 50 $\Omega$ microstrip line feed is used to excite the $\pi$-shaped slotted antenna. In the design, waveguide port excitation coefficient \(k = 8.68\) (range: 4.6–8.68) is used during port creation. In the interest of achieving of high performances, the line impedance is always taken 50 $\Omega$.

3. Results and parametric investigation

Initially, the design, parametric investigation and analysis of results of the $\pi$-shaped slotted MPA has been carried out by CST-MWS v. 2018,

| Parameter (Symbol) | Length in mm |
|--------------------|---------------|
| Leg of Isosceles triangle (C) | 15.26 |
| Base of Isosceles triangle (A) | 16 |
| Length of bar-1 (J) | 22 |
| Length of bar-2 (I) | 17 |
| Width of bar-1 and 2 (D) | 1 |
| Length of bar-3 (E) | 13 |
| Width of bar-3 (F) | 1.5 |
| Length of bar-4 (G) | 8 |
| Width of bar-4 (H) | 4.12 |
| Length of ground plane ($L_g$) | 18.2 |
| Length of the $\pi$ slot (x) | 6 |
| Width of the $\pi$ slot (y) | 1 |
| Length of leg of $\pi$ slot (z) | 3 |
Figure 5. $|S_{11}|$ of the antenna with partial ground and full ground plane.

Figure 6. $|S_{11}|$ and length of feeder of $\pi$-slotted MPA.

Figure 7. Gain and length of feeder of the $\pi$-slotted MPA.

Figure 8. $|S_{11}|$ and feeder width of the $\pi$-slotted MPA.

Figure 9. $|S_{11}|$ and length of ground plane of the $\pi$-slotted MPA.

Figure 10. Gain and length of ground plane of the $\pi$-slotted MPA.
then the designed antenna is fabricated. The properties related to port are measured by VNA and radiation properties are measured within an anechoic chamber of the antenna testing laboratory as illustrated in Figure 2. The simulated and tested reflection coefficient of the π-shaped slotted MPA with a partial ground plane for 5G/WiFi/WiMAX applications are incorporated in Figure 3. It shows the simulated and tested resonant frequency are close to each other (Simulated: 3.47 GHz and Measured: 3.51 GHz). The value of the reflection coefficient at resonant point is about -36.81 dB (simulated) and -25 dB (measured). The operating bandwidth of the π-shaped slotted MPA is approximately 2.87 GHz–5.47 GHz which covers lower 5G range (3.33–4.2 GHz), WiFi-5 (5.15–5.85 GHz) and WiMAX rel 2 (3.4–3.6 GHz) for useable 5G/WiFi/WiMAX applications and the -10 dB bandwidth is 2.6 GHz.

The benefit of applying π-shaped slot on the isosceles triangular patch is illustrated in Figure 4 by incorporating \(|S_{11}|\) curve for before and after introducing slot. The slot reduces the return loss of the MPA. The partial ground plane provides not only the wide bandwidth but also good impedance matching. Figure 5 indicates that the partial ground plane which is used to reduce the return loss as well as to tune the antenna operating band at the desired aforementioned wireless applications. In case of full ground plane the antenna resonates at 8.5 GHz with a small bandwidth but after apply partial ground plane the resonant frequency is shifted to 3.47 GHz with a very large bandwidth covering all the intended applications. The π-shaped slotted MPA shows lowest return loss (Figure 6) and better gain (Figure 7) for \(L_g = 19\) mm. The π-slotted antenna also exhibits lowest return loss for \(W_f = 2.4\) mm (Figure 8) and \(L_g = 18.2\) mm (Figure 9). With increasing \(L_g\) from 12.2 mm, the return loss is decreasing and it achieves minimum at 18.2 mm, then again loss is increasing as presented in Figure 9. For \(L_g = 18.2\) mm, the proposed π-shaped slotted antenna shows very stable gain and high efficiency over the entire operating band 2.87–5.47 GHz as illustrated in Figure 10 and Figure 11.
VSWR is a function of the property of reflection coefficient, which illustrates the signal reflected back from the tested antenna. At 3.47 GHz, the VSWR of the π-slotted MPA is 1.0293 which is less than two (1 < VSWR < 2) indicating good impedance matching throughout the 2.87–5.47 GHz as in Figure 12.

The gain and the directivity pattern of the π-slotted MPA at 3.47 GHz are illustrated in Figures 13(a) and 13(b), respectively. The gain and directivity are 2.647 dB and 3.005 dBi at 3.47 GHz. The gain of the π-slotted MPA fluctuates 2.31–3.13 dB and the directivity of the π-slotted MPA exhibits 2.62–3.41 dBi. The measured gain data also traces the simulated gain data as presented in Figure 13(c) which indicated perfect matching between simulated and tested data.

The fields (both electric and magnetic) at ϕ = 0° and 90° are represented in Figure 14. Main lobes of the E-field and H-field patterns are focused at (170°, 180°) and (84.4°, 180°) at ϕ = (0°, 90°). The magnitudes are (17.4 dB V/m, 17.2 dB V/m) and (−34.1 dBA/m, −34.3 dBA/m) at ϕ = (0°, 90°). The half power beamwidth or 3 dB angular beam width is 84.4° and the side lobe level is -1 dB. From the configuration of omnidirectional radiation patterns, the proposed antenna radiates in all directions perpendicular to the x-axis. Therefore, from the presented analysis, it is the suitable omni-directional MPA for the lower 5G/WiFi/WiMAX applications.

The efficiency is defined as the ratio of the radiated power to the total power supplied to the metal patch at a given frequency. The π-slotted MPA possesses an efficiency of 90.88% at 3.47 GHz. The π-slotted MPA exhibits radiation efficiency 90.07–93.797% (simulated) and 80–84.3% (measured). The measured and simulated efficiency slightly differs due to soldering error in the fabricated prototype. The measured efficiency also shows a great stability as simulated data over the entire 2.87–5.47 GHz operating band shown in Figure 15. The distribution of surface current of the π-shaped slotted MPA at 3.47 GHz is maximum (63.3448 A/m) at the lower part of the feed line and the lower edges of the patch as depicted in Figure 16. The deployment of four different sized parallel bars in between the main part of the isosceles triangular patch and microstrip feed line creates corrugation in both sides. The surface current density gets slightly higher in the corrugation region which improves the radiation pattern. Another important impedance property (Z-matrix) of the π-slotted MPA are highlighted in Figure 17 which specifies that the real part of Z-parameter is close to 50 Ω and the imaginary part of Z-parameter is close to 0 at 3.47 GHz. The impedance Z = (50.308.1.436) certifies that the proposed antenna is close to a pure resistive device and good impedance matching indicator. A comparison Table 3 shows the compatibility and strengths of the proposed π-slotted patch antenna. Our proposed π-shaped slotted patch antenna shows maximum bandwidth (2.6 GHz) with a compact size and very good radiation characteristics like VSWR, reflection coefficient, gain as well as efficiency.
Table 3. Comparison table.

| Parameter                        | Reference No. | This work |
|----------------------------------|---------------|-----------|
|                                | [8]           | [9]       | [13]      | [14]      | [16]      | [17]      | [18]      | [19]      | [20]      | [21]      |
| Size (L x W x h) mm³             | 30 x 20 x 1.5 | 36 x 16 x 1.6 | 31 x 16 x 1.6 | 22 x 24 x 0.25 | 44 x 40 x 1.6 | 45 x 44.92 x 1.6 | 35.5 x 40.11 x 1.6 | 76 x 42 x 1.6 | 150 x 75 x 1.6 | 36 x 24 x 1.5875 x 1.6 | 35 x 31 x 0.79 |
| Substrate material               | FR4           | FR4       | FR4       | Rogers RT 5880 | FR4       | FR4       | FR4       | FR4       | FR4       | Rogers RT 5880 |
| Centre frequency                 | 3.15-5.55     | 3.3-4.00  | 3.29-3.63, 4.5-5.2| 2.9-4.4    | 2.62-5.2  | 3.54-5.48  | 2.8-4.6  | 1.341-3.834 | 3.21-3.81  | 3.36-3.715  | 2.87-5.47  |
| Reflection coefficient (dB)      | ~-32          | ~-31.15   | ~-21      | ~-28.76    | ~-41      | ~-41.28   | ~-43       | ~-34       | >10        | ~-55      | ~-36.81   |
| Gain (dBi) at centre frequency   | 2.35          | 2.5       | 2.71       | 2.52       | 2.96      | 3.47       | 5.1        | 1.89       | ~3.19      | ~3.64     | 2.1        | 2.647     |
| BW (GHz)                         | 2.4           | 0.70      | 0.34, 0.9  | 1.5        | 2.58      | 2.48       | 1.8        | 2.493      | 0.60       | 0.355     | 2.6        |
| VSWR                             | NA            | <2        | NA        | <2         | <2        | NA        | 1.5       | <1.5       | NA         | 1.0037   | 1.0293    |

*NA = Not available.

4. Conclusion and discussion

A π-shaped slotted patch antenna with a partial ground structure is proposed for 5G/WiFi/WiMAX applications. The antenna consists of an isosceles triangular patch with a π-slot, four parallel bars placed in the bottom of the patch and a 50 Ω microstrip feed line. Both the π-shaped slot on the isosceles triangular patch and partial ground are the key factors for the enhancement of wide bandwidth and low return loss. In addition, the antenna offers an omni-directional pattern, reasonably overall volume of 857.15 mm³ and easy to construct. The proposed MPA’s operating frequency ranges from 2.87–5.47 GHz which satisfies for lower 5G/WiFi/WiMAX applications. The antenna is resonated at 3.47 GHz with a gain of 2.647 dB, directivity of 3.005 dBi, VSWR of 2.52, 7.17 2.52, BW (GHz) 2.4, 0.70, 0.34, 0.9, 1.5, 2.58, 2.48, 1.8, 2.493, 0.60, 0.355, 2.6, VSWR NA <2, NA <2, NA <2, NA 1.5, <1.5, NA 1.0037, 1.0293.

Declarations

Author contribution statement

Liton Chandra Paul; Md. Tanvir Rahman Jim; Tithi Rani: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sarker Saleh Ahmed Ankan: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Sajeed Chandra Das: Performed the experiments; Analyzed and interpreted the data.

Himel Kumar Saha: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supporting material/referenced in article.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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