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REGULAR ARTICLE

A Low-Profile Crescent Shaped Circular Patch Antenna for Sub-6 GHz Applications

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Compact-sized circular patch antennas are used in satellites, mobile networks, radars, and other current and future wireless communications applications. In this paper, a low-profile crescent-shaped circular patch antenna with an inset feed for sub-6 GHz wire-free communication applications is examined. The basic design of a crescent-shaped circular patch antenna included a full ground. Following that, a defective ground structure is used to achieve a broader bandwidth. HFSS is used to examine a crescent-shaped microstrip circular patch antenna. A 3 dBi gain of 3.05 dB was achieved at 3.5 GHz, with a reflection coefficient of – 22.7 dB and a fractional bandwidth of 42.85 %. The crescent-shaped circular patch antenna contains a dimension of $31 \times 28 \times 1.6$ mm^3 and is printed on a FR4 epoxy dielectric material. The crescent-shaped CPA is simulated using FR4 epoxy as a dielectric with a loss tangent of 0.02, dielectric constant of 4.4, and thickness of 1.6 mm. PEC (perfect electric conducting) material is chosen as a conducting layer. Based on the simulation results, the circle patch antenna in the shape of a crescent is good for N77 and N78 sub-6GHz uses. The proposed antenna is optimized through a series of iterative procedures. The crescent-shaped CPA is composed of a concentric circular patch joined by a crescent-shaped patch. The proposed crescent-shaped CPA is simulated using the finite element method (HFSS). From the results it is a fact that the proposed crescent shaped antenna is well suited for sub-6GHz 5G applications.

Keywords: Antenna, Crescent-shaped, Reflection coefficient, Bandwidth, Sub-6 GHz 5G, N77 and N78 bands.

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1. INTRODUCTION

Technology is currently in high demand due to the various benefits they offer, such as high data capacity, low latency, and quick data rate [1]. Mobile communication technologies have undergone tremendous advancements over the past few years with the coming of 5G. N77, N78, and N79 are the frequency bands that are included in 5G New Radio for applications that operate at frequencies below 6 GHz [2, 3]. The conventional patch antenna, because of its numerous advantages, including being lightweight, tiny, inexpensive, having lower dimensions and having a low profile [4], can be used for various microwave, millimeter and terahertz applications. Traditional microstrip antennas have a small bandwidth and low gain, which are their major shortcomings [5]. Despite this, the MPA may be configured to operate at numerous operating frequencies, making it appropriate for a wide range of wireless applications using a single antenna. It is now possible for patch antennas to resonate at a greater number of bands, have a wider bandwidth, achieve higher gain, and be more compact [6-12]. Academics have developed these novel designs in recent years. Teflon was used in the design of the MPA, which has dimensions of 50 millimetres by 80 millimetres and operates in various frequencies that fall under the sub-6 GHz 5G spectrum [6]. 2.50 GHz, 3.51 GHz, and 4.67 GHz are the frequencies at which the antenna achieves gains of 2.01 dBi, 3.2 dBi, and 2.25 dBi, respectively. wide bandwidth of 2.56 GHz is possessed by the antenna, despite the fact that it only has a gain of 2.44 dBi. The DGS method was utilized in [7] to achieve resonance at two distinct frequencies, namely 4.51 GHz and 4.89 GHz, by employing the RO5880 substrate, which possesses an ε_r of 2.2. The ATD3-KBDRL method was implemented to enhance the bandwidth of a patch antenna by 39.18 % [8]. The effectiveness of communication systems operating at 5G sub-6 GHz has been significantly improved because of recent developments in MPA design. Using an Arlon AD300C substrate, a single-band antenna was presented in [9]. This antenna had a gain of 2.5 dBi at 5.65 GHz. To increase the gain of MPAs that are operating at 2.4 GHz, the airgap technique was described in [10]. This technique includes generating an air gap between the substrate and the ground plane. A three-millimeter air gap was introduced, which resulted in an increase in gain from 2.5 dBi to 2.81 dBi. On the other hand, the bandwidth reduced from 11.7 GHz to 7.2 GHz. The study found that this method compromises antenna gains

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and bandwidth. A further method for enhancing the gain of an antenna is to include a reflective layer, as demonstrated in [11], which incorporates four spacers across each of the patch antenna's four corners. The antenna has a gain of 5 dBi and runs at 2.5 GHz. It has a narrow bandwidth of 0.47 MHz and operates at that frequency. These are the dimensions of the item: 60 millimetres by 55 millimetres by 8 millimetres. Additionally, a wideband antenna measuring 28 millimetres by 20 millimetres was developed in [12] by employing FR-4 substrate to operate in the n77 and n78 bands of 5G New Radio. There were a gain of 2.2 decibels and a bandwidth of 700 megahertz for the antenna. This article describes a microstrip circular patch antenna in the shape of a crescent moon set inside of a concentric circular patch. This antenna aims to address the previously discussed obstacles. For achieving high gain and a wider bandwidth, the design incorporates a circular patch that is coupled to a transmission line with a 50Ω impedance. Additionally, DGS has been used.

2. ANALYSIS OF CRESCENT-SHAPED PATCH ANTENNA (CPA)

2.1 Evolution Procedure of the Antenna

Initially, a microstrip transmission line measuring 15 × 4 mm² was connected to a circle with an 8 mm radius. Step 2 involves subtracting a circle with a radius of 5 mm from the antenna design in step 1. Step 3 presents by subtracting a circle having a radius of 3 mm from a 4 mm radian circle forming a crescent shaped patch with a fully ground copper plane. To obtain a wider bandwidth and high gain, a rectangle of 28 mm in length and 6.5 mm in width was removed from the ground plane at final step (step 4).

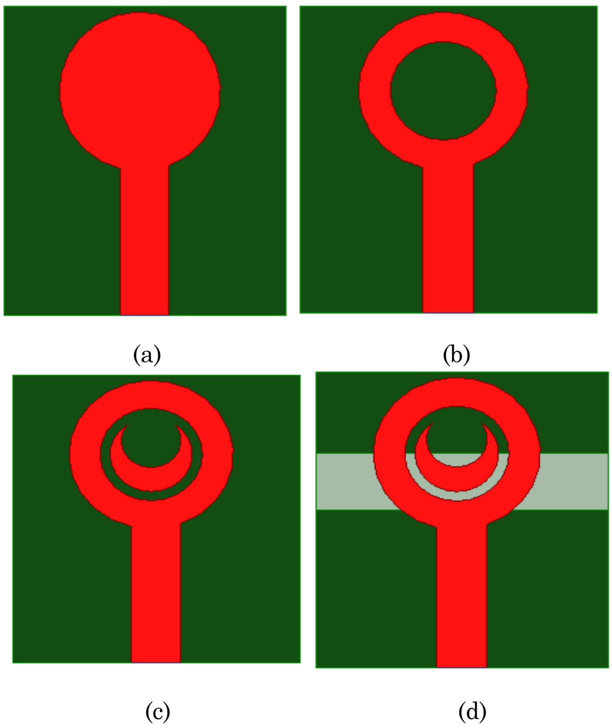


Fig. 1 – Evolutionary process (a) Step 1 (b) Step 2 (c) Step 3 (d) Step 4

The crescent-shaped CPA with DGS at different stages of evolution is shown in Figure 2 by way of S11. At its resonance frequency of 3.8 GHz, the Step 1 antenna exhibits an S11 of – 19 dB. To generate the step 2 antenna, which has a resonance frequency of 3.55 GHz and an S11 of – 20 dB, a circle is subtracted from the step 1 antenna. The step 3 antenna has a resonance frequency of 3.5 GHz and an S11 of – 21 dB. It is made by adding a crescent-shaped patch to the design of the step 2 antenna. Finally, a microstrip rectangle has been removed from the ground plane in order to provide a greater bandwidth. The 5G Sub-6 GHz channels (N77 and N78 bands) are well-suited to the 3.5 GHz (3.0-4.5 GHz) resonance frequency of the step 4 antenna, which has an S11 of – 22.7 dB.

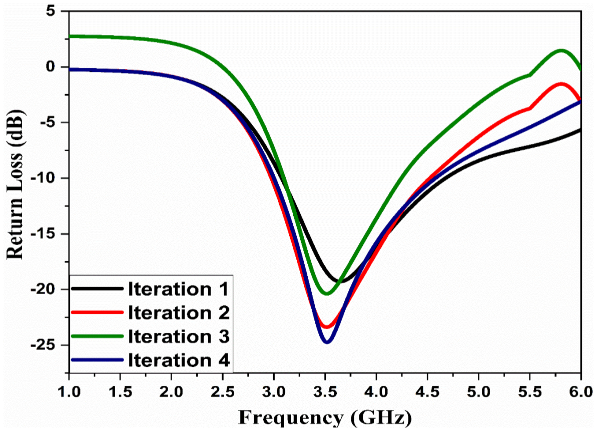
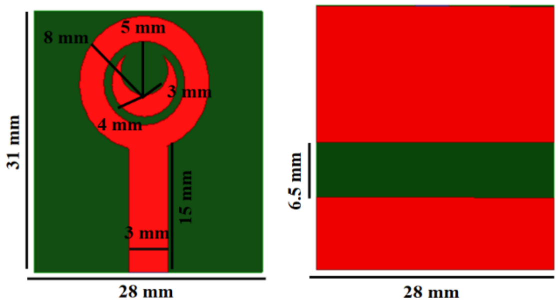


Fig. 2 – Obtained S11 for all iterations including proposed

The geometrical configuration of the crescent-shaped patch antenna (CPA) is shown in Figure 3. FR4 epoxy, which has a loss tangent of 0.02, ε_r of 4.4, and a thickness of 1.6 mm, is used to simulate crescent-shaped CPA. The crescent-shaped CPA is made up of a concentric circular patch connected by a crescent-shaped patch. The finite element method (HFSS) is used to simulate the crescent-shaped CPA. The dimensions of the H-shaped MCPA are 31 mm in length, 28 mm in width, and 1.6 mm in height.

3. RESULTS AND DISCUSSIONS

By employing the feed line width, the crescent-shaped CPA can be parametrically analyzed, as shown in Figure 4. Figure 5 clearly shows that the impedance matching increased as the feed line width increased. Impedance matching is best accomplished with a 4 mm feed line width. The use of a feed line width of 3 millimeters demonstrates that the structure can achieve resonant performance in the band that was designed for it. By employing a defective ground structure, the return loss was improved and the crescent-shaped CPA was able to reach the intended resonant frequency band with a wide bandwidth. Figure 4 also illustrates how the improved impedance bandwidth can be increased to 1.5 GHz by changing the feed line's length, making it appropriate for N77 and N78 Sub-6GHz applications. Figure 5 displays the simulated S_{11} of the crescent-shaped CPA. Figure 4 illustrates that the crescent-shaped CPA, which resonates at 3.5 GHz with an S11 of – 22.7 dB with obtained VSWR of 1.15, which is less than 2, at the operating frequency of 3.5 GHz which is suitable for N77 and N78 Sub-6GHz applications. Figure 5 displays the simulated parametric analysis of the crescent-shaped CPA. The crescent-shaped CPA offers a peak resonant frequency when feed width is 3 mm which is shown with green color.



(a) (b)

Fig. 3 – Proposed crescent shaped patch antenna (CPA) with dimensions

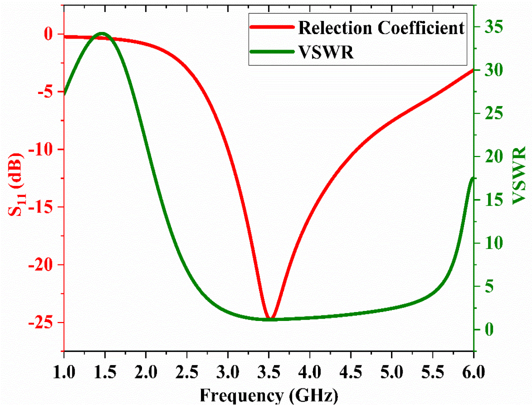


Fig. 4 – S11 of crescent shaped CPA

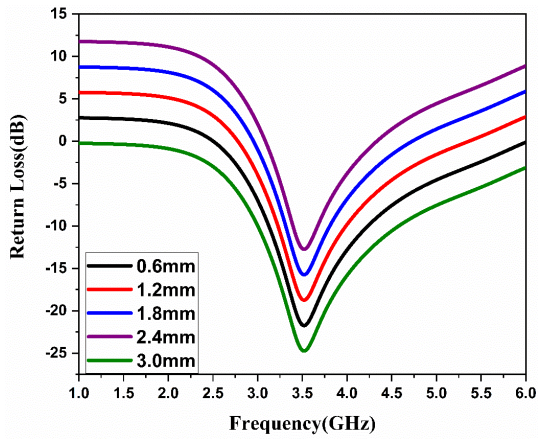


Fig. 5 – Parametric analysis by varying feed width

Gain of the crescent-shaped CPA is shown in Figure 6, and a maximum value of 3.05 dBi has been noted. Figure 7 (a) displays the *E*-field distribution of the antenna at 3.5 GHz. At a resonant frequency of 3.5 GHz, red represents the maximum field distribution; a maximum value of 500 Am^{-1} has been recorded. Figure 7 (b) displays the crescent-shaped CPA current distributions. Figure 8 displays the radiation efficiency of the crescent-shaped CPA. From Figure 8, it is clear that the proposed antenna achieves 87 % radiation efficiency has been attained at the resonance frequency.

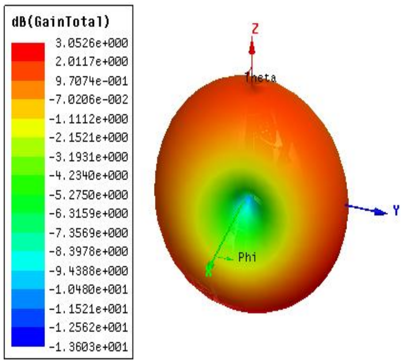
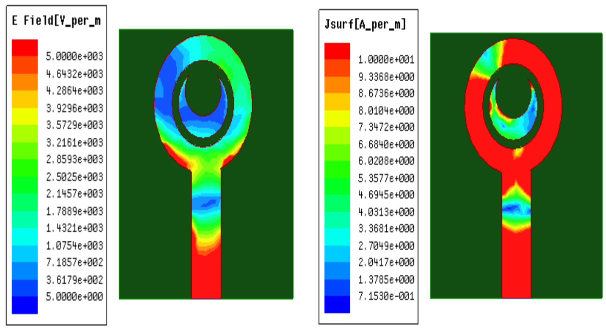


Fig. 6 – 3 dBi gain of Crescent-shaped CPA



(a) (b)

Fig. 7 – Proposed design (a) *E*-field distribution (b) *J*- surface distributions

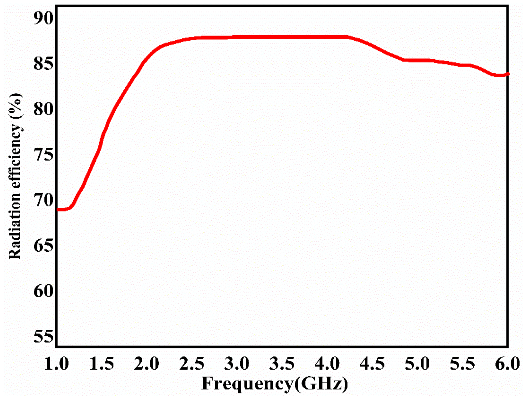


Fig. 8 – Radiation efficiency of the Crescent-shaped CPA

4. CONCLUSIONS

A low-profile crescent shaped circular patch antenna is analyzed for wireless communication applications. Crescent shaped microstrip circular patch antenna is analyzed using HFSS. 3 dBi gain of 3.05 dB has been obtained at a resonating frequency of 3.5 GHz. Reflection co-efficient of – 22.7 dB has been obtained with a fractional bandwidth of 42.85 % at the operating frequency. The proposed crescent-shaped CPA is a suitable model for N77 and N78 5G-Sub-6GHz wireless communication applications because of its wider bandwidth and high gain.

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Низькопрофільна кругла патч-антена у формі півмісяця для застосувань у діапазоні менше 6 ГГц

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Компактні круглі патч-антени використовуються в супутниках, мобільних мережах, радарах та інших сучасних та майбутніх застосуваннях бездротового зв’язку. У цій статті розглядається низькопрофільна кругла патч-антена у формі півмісяця з вставленим живленням для застосувань бездротового зв'язку на частоті менше 6 ГГц. Базова конструкція круглої патч-антени у формі півмісяця включала повне заземлення. Після цього для досягнення ширшої смуги пропускання використовується дефектна структура заземлення. Для дослідження мікросмужкової круглої патч-антени у формі півмісяця використовується високоякісний полімерний матеріал (HFSS). На частоті 3,5 ГГц було досягнуто коефіцієнта підсилення 3 дБі на рівні 3,05 дБ з коефіцієнтом відбиття – 22,7 дБ та частковою смугою пропускання 42,85 %. Кругла патч-антена у формі півмісяця має розміри 31 × 28 × 1,6 мм^3 та надрукована на епоксидному діелектричному матеріалі FR4. Серповидна CPA змодельована з використанням епоксидної смоли FR4 як діелектрика з тангенсом кута втрат 0,02, діелектричною проникністю 4,4 та товщиною 1,6 мм. Як провідний шар обрано матеріал PEC (ідеальна електропровідність). Виходячи з результатів моделювання, кругла патч-антена у формі півмісяця добре підходить для використання в N77 та N78 в діапазоні нижче 6 ГГц. Запропонована антена оптимізована за допомогою серії ітераційних процедур. Серповидна CPA складається з концентричної кругової ділянки, з'єднаної з ділянкою у формі півмісяця. Запропонована серповидна CPA змодельована за допомогою методу скінченних елементів (HFSS). З результатів видно, що запропонована серповидна антена добре підходить для застосувань 5G в діапазоні нижче 6 ГГц.

Ключові слова: Антена, Серпоподібна, Коефіцієнт відбиття, Пропускна здатність, Діапазони 5G до 6 ГГц, N77 та N78.