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REGULAR ARTICLE

Flexible Material Based Broadband Antenna for Both C-and X-band Applications

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The proposed antenna contains a rectangular patch with semicircular slots on four corners to it for achieving a broader bandwidth. The bending analysis is done for the proposed antenna to show the antenna performance irrespective of any bending angle. A broad bandwidth can be achieved by introducing semicircular slots for each of its four sides. The prescribed antenna is designed on polyimide substrate, which had a permittivity of 3.5 and loss tangent of 0.0027. The copper material thickness contains 0.035 mm. The proposed antenna contains an overall size of 15 × 13 × 0.2 mm³. The simulated results confirm that the proposed antenna possesses peak resonant frequency at 8.2 GHz and operates from 5.6 to 9.6 GHz with a bandwidth of 4 GHz. In addition to having a bandwidth of 4 GHz, the suggested design also had an S11 value of – 27 dB and a VSWR value of 1.09 at the resonance frequency. Up to a bending angle of 30 degrees, the proposed antenna is achieving same response with a minor difference. Additionally, the proposed antenna consists of a gain of 7.6 dBi, and it has a radiation efficiency of 96 %. Analysis of the field and current distributions is presented in this article to show the effectiveness of the proposed antenna.

Keywords: Bandwidth, Broadband, *S*-parameter, Return loss, VSWR.

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1. INTRODUCTION

For high-frequency applications like radars and satellite communications, these patch antennas work best in the X and C band applications. Monopole patch antennas are crucial to wireless communication systems because of their ease of integration, versatility, and simplicity. In numerous microwave frequency applications, compact wideband monopole antennas are now essential due to the growing demand for quicker data transfers and stronger connectivity. The most straightforward manufacturing method that yields good outcomes is the microstrip feedline approach. It is challenging to integrate this antenna with MMIC technology chips due to its distinct radiating patch and ground plane. There is also the option of using a CPW feed. Since the ground and radiating patch of the CPW feed are on the same plane, it is perfect for integration with MMIC circuits. The design of wearable and flexible antennas gets much more sophisticated when considering satellite communication systems. These antennas provide outstanding performance and adapt to body movements while integrating flawlessly with peripheral technology. Their innovative design techniques and use of flexible materials allow them to continue sending and receiving signals effectively even when bent or stretched. Radar and satellite communication applications require this flexibility.

Microstrip antennas are compatible with a broad variety of electrical equipment, are small in height and breadth, and are commonly employed in GHz frequency applications because of these qualities. A conducting patch and a ground plane are located on opposite sides of a dielectric substrate in a microstrip antenna. It is another common practice to feed the conducting patch using a coaxial wire [1] or microstrip line [2]. The patch's size determines the microstrip antenna's operating frequency [3]. When the patch size is smaller, the operating frequency is greater; when the patch size is larger, the operating frequency is lower. In GHz frequency applications, slot antennas are an additional kind of MIMO antenna. Slot antennas are made of a metal plate with a thin aperture or slot in the middle. Typically, a coaxial wire or a microstrip line is used to excite the slot. Slot antennas have a broad bandwidth and are simple to construct [4]. Higher frequencies cause electromagnetic waves to have shorter wavelengths, hence in order to get the necessary performance, antenna size must be proportionately decreased. This can be difficult because smaller antennas

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often have less gain and efficiency than bigger antennas. Therefore, antennas need to be designed to maximize efficiency, gain, and size trade-offs [5]. Antennas should generally radiate in a way that minimizes interference between the various antenna elements and maximizes signal strength. The antenna elements must be carefully designed and positioned within the array in order to achieve this [6]. To optimize signal strength in the intended direction while reducing interference with other antennas, directional antennas with a small beamwidth are a popular method [7]. There are several different types of antennas for GHz applications, such as patch antennas [8] and dipole antennas [9]. A slot-modified antenna design is described by Som Pal Gangwar et al. [10] for dual-band wireless applications. Using three distinct kinds of slots, [11] developed a compact, switchable, hexagonal-shaped monopole antenna measuring 36 × 36 × 1.6 mm^3 that can operate in both multiband and ultra-wideband frequencies. The researchers from [12-14] use reconfigurable antennas, and these structures offer good performance for multifrequency operations. A monopole antenna with a flexible rectangular shape is suggested in this paper. It uses a CPW feeding structure. Flexible antennas work well with the CPW feeding structure since they are thinner and more bendable. It has benefits for impedance matching as well. To improve bandwidth and return loss, semicircular slots are incorporated into the inner rectangular patch.

2. DESIGN METHODOLOGY

Figure 1 illustrates the proposed design, which comprises of a rectangular patch with a semicircular slot type antenna. The middle polyimide layer in the conventional design measures 15 × 13 × 0.2 mm^3. It makes use of a radiating patch composed of copper that has a volume of 12 × 11 × 0.035 mm^3. Figure 1 shows the dimensions (mm) of the suggested structure.

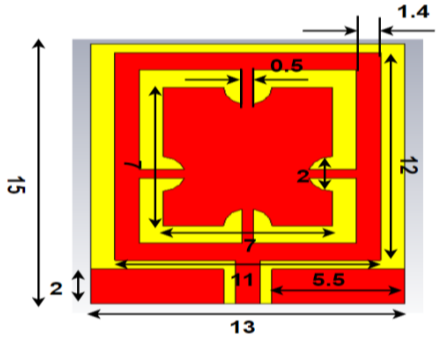


Fig. 1 – The proposed antenna's front view

The CST tool is used to tackle electromagnetic problems that require precise and fast simulation results. The main benefit of this tool is that it has simple needs for resources to scale linearly with relation to the number of nodes in the mesh. This makes controlling massive radiating structures easy and effective.

2.1 Step by Step design Approach

The approaches that were taken into account for constructing the suggested antenna are shown in Figures 2 (a-d). Rectangular radiating patches are used in the fundamental design, as shown in Figure 2(a). The second step of the design process entails adding a second rectangular patch inside the first patch as depicted in Figure 2(b). The third stage involves adding a semicircular slit on four sides of the inner rectangular patch, as illustrated in Figure 2(c). In the fourth and final step, a rectangle patch is inserted to join the inner and outer rectangular patches, as illustrated in Figure 2(d). The proposed design's return loss plot for various construction elements is shown in Figure 3. The maximum return loss occurs in the final step.

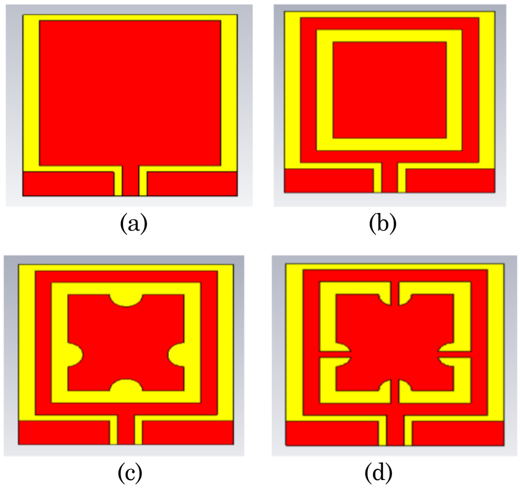


Fig. 2 – Construction of the suggested antenna using various design stages (a) Step-1 (b) Step-2 (c) Step-3 (d) Step-4

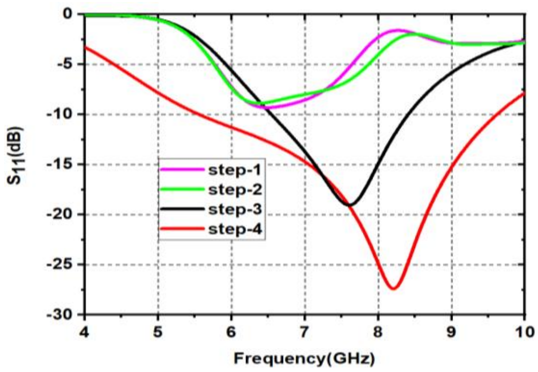
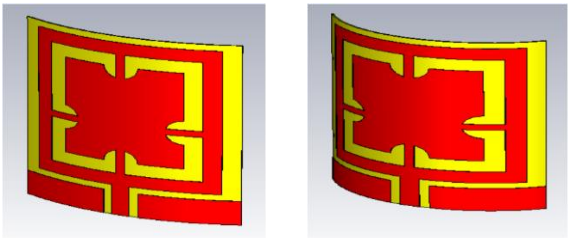


Fig. 3 – The prescribed design S_{11}(dB) vs frequency plot for various iteration steps

3. BENDING ANALYSIS

The antenna's *S*-parameter changed when it was bent. The *S*-parameter modified slightly as a result of being measured in accordance with the intended antenna's degree of horizontal bending. It is evident that the suggested antenna works well as a flexible antenna. This is because, in contrast to a flat antenna, the resonant frequency and bandwidth do not vary much depending on the amount or direction of bending. Figure 4(a-b) illustrates the 15° and 30° horizontal bending of the specified structure. Figure 5 shows the relative return loss response at different bending angles.



(a) (b)

Fig. 4 – Proposed design horizontal bending of (a) 15° and (b) 30°

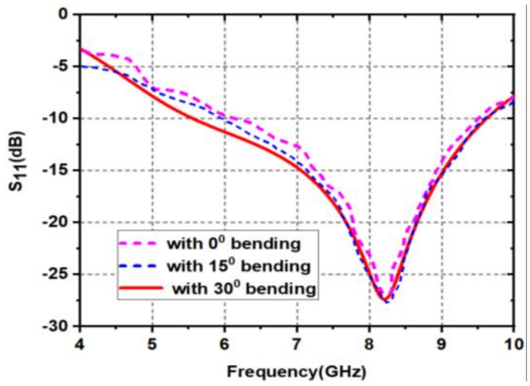


Fig. 5 – Obtained S_{11} plot for various bending angles in horizontal direction

4. RESULTS AND DISCUSSIONS

The antenna was designed using the process depicted in Figure 2, and Figure 3 displays the antenna's S-parameter based on each approach. A CPW feeding technique was used to develop the antenna using a rectangular patch monopole, as seen in Figure 2(a). There is no resonance with this rectangular patch. An additional rectangular patch is added inside the patch with semicircular slots, as illustrated in Figure 2(c), to increase the performance of an antenna. Consequently, the antenna has a bandwidth of about 2GHz and a resonance frequency of 7 GHz with a return loss of -15 dB. A small rectangular patch with 0.5 mm thick, is placed between the inner and outer rectangular patches to increase bandwidth and return loss. The proposed antenna resonates at 8.2 GHz from 5.6 to 9.6 GHz with an improved return loss of – 27 dB as shown in Figure 6.

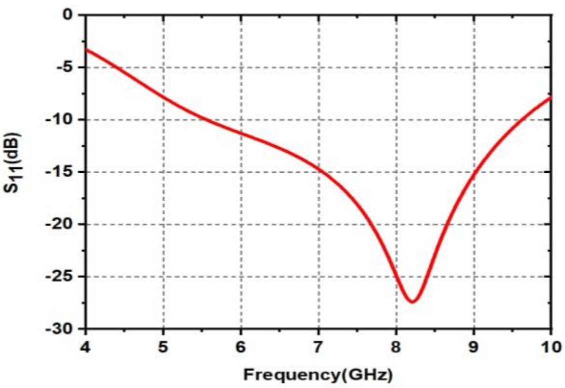


Fig. 6 – Obtained S_{11} plot for the proposed antenna

Figure 7 shows the VSWR of the prescribed design. The VSWR values are below 2 across the whole operational bands' resonance frequency, as this Figure 7 illustrates. In order to efficiently couple electromagnetic (EM) energy into the proposed antenna, the feed length is tuned and a thorough examination of the microstrip feed with a rectangular patch is carried out. The VSWR value at resonance is 1.09, as shown in Figure 7. This indicates that during resonance, the suggested antenna has the least amount of reflection.

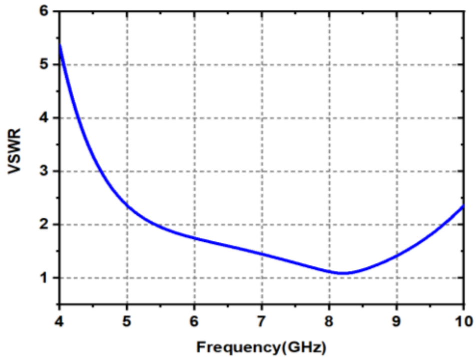


Fig. 7 – VSWR Plot for the proposed antenna

Figure 8 illustrates the high radiation efficiency (Red colour line) of 96 % at resonance and the excellent peak gain (Black colour line) of 7.6 dBi at resonance produced by the suggested design operating at 8.2 GHz.

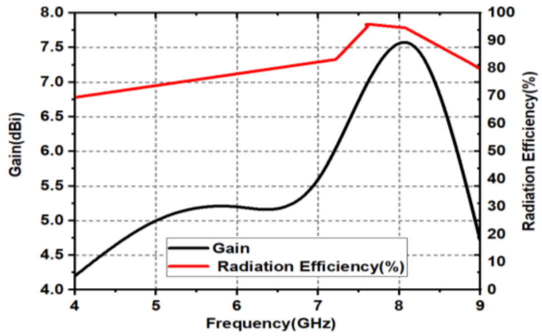
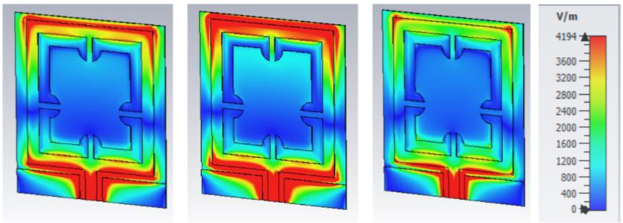


Fig. 8 – Peak gain and Radiation efficiency plot

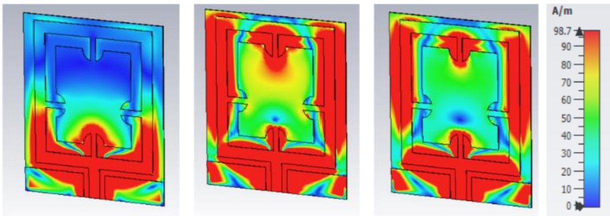
4.1 Various Distributions and Analysis

Figure 9(a) shows that in the vertical direction of the antenna, the electric field intensity is lowest at 7 GHz and 9 GHz at the outside rectangular radiating patch. The upper and lower sides of the outside rectangular patch, as well as the left and right sides of the feed point, exhibit a greater electric field at 8.2 GHz, as illustrated in Figure 9(b). A minimum magnetic field can be seen in Figure 10(a) surrounding the feeding point and on the patch's lower side. This field extends horizontally along the antenna at 7 GHz. Figure 10(b) shows that at 8.2 GHz, the magnetic field is stronger than at 7 and 9 GHz. As a result, the magnetic and electric fields propagate in opposite directions. The feed line exhibits the highest current distribution when operating at 8.2 GHz, as shown in Figure 11(a-c). Compared to 8.2 GHz, the radiating patch's upper side exhibits the lowest current distribution at 7 and 9 GHz.



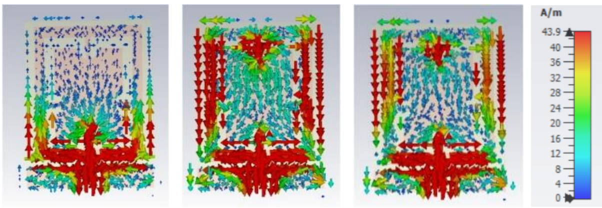
(a) (b) (c)

Fig. 9 – Distribution of *E*-field at (a) 7 GHz (b) 8.2 GHz (c) 9 GHz



(a) (b) (c)

Fig. 10 – Distribution of *H*-field at (a) 7 GHz (b) 8.2 GHz (c) 9 GHz



(a) (b) (c)

Fig. 11 – Surface Current Distribution at (a) 7 GHz (b) 8.2 GHz (c) 9 GHz

4.2 Performance Comparison with Other Reported Works

Table 1 presents a comparison between the performance of the proposed antenna and the literature. The suggested rectangular semicircular-slot patch antenna maintains a small dimension while providing excellent gain and radiation efficiency.

Table 1 – Comparison with recent research findings

Ref.	Year of Pub.	Ant. Size (mm^2)	S_{11}(dB)	Gain (dBi)	Radiation Efficiency
[2]	2022	150 × 75	– 23	3.5	75
[4]	2022	70 × 65	– 25 and – 33	1.93 and 3.11	NM
[9]	2023	66 × 66	– 40	11	88
[1]	2022	62 × 62	– 35	7	NM
[3]	2022	48 × 34	– 40	4.78	72
[14]	2024	27 × 27	– 18 and – 32	2.65 and 2.84	95 and 73
This Work	–	15 × 13	– 27	7.6	96

*NM-Not Mentioned

5. CONCLUSIONS

In this paper, we suggested a flexible, miniature broadband antenna that can be applied to various band applications. The suggested antenna has a rectangular patch with a semicircular slot that is based on a monopole. This allows it to resonate in a larger band. The antenna operates at 8.2 GHz with a return loss of – 27 dB and has a bandwidth of 4 GHz (5.6 to 9.6 GHz). The antenna's substrate is made of polyimide with 0.2 mm thick, to allow for enough bending. The proposed structure achieves a VSWR of 1.09, radiation efficiency of 96 %, and maximum peak gain of 7.6 dBi. In addition, The *S*-parameter was measured in accordance with the antenna's bending degree and bending direction in order to examine the bending properties of the device. The antenna's ability to resonate identically when bent and flatened verified that it was appropriate for use as a flexible antenna. The overall size of the antenna is 15 × 13 × 0.235 mm^3. The proposed antenna can be used for C- and X-band applications.

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Гнучка широкосмугова антена для застосувань у С-діапазоні та Х-діапазонах

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Запропонована антена містить прямокутну пластину з напівкруглими прорізами на чотирьох кутах для досягнення ширшої смуги пропускання. Аналіз вигину проведено для запропонованої антени, щоб показати її характеристики незалежно від кута вигину. Широкої смуги пропускання можна досягти, ввівши напівкруглі прорізи на кожній з чотирьох її сторін. Запропонована антена розроблена на поліімідній підкладці з діелектричною проникністю 3,5 та тангенсом кута втрат 0,0027. Товщина мідного матеріалу становить 0,035 мм. Загальний розмір запропонованої антени становить (15 × 13 × 0,2) мм^3. Результати моделювання підтверджують, що запропонована антена має пікову резонансну частоту на частоті 8,2 ГГц та працює від 5,6 до 9,6 ГГц зі смугою пропускання 4 ГГц. Окрім смуги пропускання 4 ГГц, запропонована конструкція також мала значення S11 – 27 дБ та значення КСХН 1,09 на резонансній частоті. До кута вигину 30 градусів запропонована антена досягає такої ж характеристики з незначною різницею. Крім того, запропонована антена має коефіцієнт підсилення 7,6 дБі та ефективність випромінювання 96 %. У цій статті представлено аналіз розподілу поля та струму, щоб показати ефективність запропонованої антени.

Ключові слова: Пропускна здатність, Широкосмуговий зв’язок, S-параметр, Втрата зворотного зв’язку, VSWR.