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RESEARCH ARTICLE

Comparative study of single-slot and multi-slot graphene-based microstrip patch antenna for X-band application

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HIGHLIGHTS

> Microstrip patch antenna was designed and simulated using Duroid as a substrate with graphene as a conductive patch material. Four different models were designed and simulated with different slots which includes 1,2 3 and without slot of different dimensions. The single-slot based antenna showed better performance in terms of gain and bandwidth. The antenna can be used for X-band applications.

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ABSTRACT

Microstrip patch antennas can be made from a variety of materials with varying dielectric constants. In this article, a modified multi-slot patch multiband antenna is simulated using CST. Graphene is proposed as a patch material for an antenna that is designed to be used and studied at X and Ku band frequencies. Because of graphene's high conductivity, it is appealing to use it as a conductive patch material to replace copper and other metal conductors while also increasing the antenna's bandwidth and radiation efficiency. On the patch, different sized slot cuts were made. The antenna is made of Duroid RT5880 (lossy) material with a dielectric constant of 2.2 that is sandwiched between a graphene patch and a ground plane. The antenna resonated at 11.22 GHz, indicating that it could be used in the X band frequency range.

1. Introduction

Microstrip patch antennas (MPA) were introduced in the 1950s and quickly became one of the most rapidly evolving devices in radio frequency engineering. This is due to communications' rapid advancement [1,2]. The advantages that made the microstrip radio wire noticeable are that it is moderately simple to construct, reasonable, lightweight, and has a slim bulge from the surface. These MPAs have well-known frequencies that exceed 100 MHz. The receiving wire for the fix is made on a dielectric substrate [3]. Nanotechnology is a cutting-edge method of technological advancement that involves the management of material at the nanoscale (1 billion times smaller than a meter) [4]. Nanotechnology truly encompasses the creation and application of chemical, physical, and organic frameworks at scales ranging from single particles or molecules to submicron levels, as well as their integration into larger frameworks to form nanomaterials [5]. Nanomaterials are materials with a thickness of less than 100 nanometers. Nanomaterials, such as graphene, frequently fall into different dimensional categories, such as 2D, 1D, or 0D [6].

Graphene is rapidly becoming an extremely appealing material for a wide range of electronic components, circuits, systems, and devices, including frequency multipliers, metamaterials, organic electronics, high frequency field effect transistors (FET), wireless nano-sensors, modulators, transparent solar cells, and terahertz devices [7]. It has excellent performance with much lower power consumption, as well as the option of fabricating it using advanced silicon device (CMOS) fabrication technology [1,2].

Enhancing bandwidth is a critical requirement for the practical application of microstrip patch antennas [8]. Bandwidth enhancement techniques include using a material with a lower dielectric constant, partial grounding, creating and/or enlarging the antenna's inset gap, and utilizing the defective ground structure (DGS) [7,9]. Adjacent slots were introduced to the patch in this paper, significantly increasing the antenna bandwidth. The X-Band frequency range, as

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defined by IEEE Standard in 2002, ranges from 8 to 12 GHz. This frequency range is widely used in radar applications, air traffic control, military satellite, weather forecasting and monitoring, radio-determination purposes, defense, and law enforcement vehicle speed tracking [10].

2. Methodology

The antenna is designed using the standard design equations [3]. Table 1 summarizes and presents the design parameters. Figures 1–4 show the antenna being simulated in CST design studio. Figure 1 depicts a conventional rectangular antenna, while Figure 2 depicts an MPA with a single rectangular slot cut at the top right hand corner of size 1mm by 4mm. Figure 3 depicts the MPA with two rectangular slots on the top right and bottom left sides. Figure 4 depicts the MPA with three rectangular slots, the third of which is cut in the patch element's center.

Table 1. Design parameters of the Antenna

S/No.	*Parameters*	*Dimension (mm)*
1	Substrate width	21
2	Substrate length	19
3	Patch width	12
4	Patch length	9
5	Feedline width	6
6	Feedline length	3
7	Slot width	4
8	Slot length	1
9	Substrate thickness	1.57
10	Ground/Patch thickness	0.02

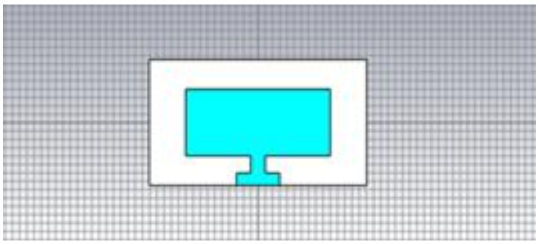

Figure 1. Conventional MPA

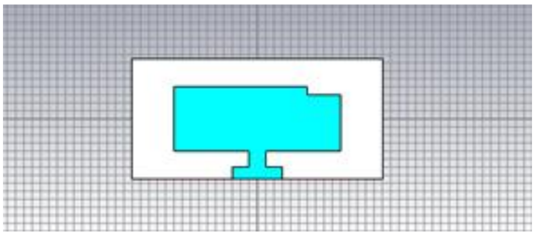

Figure 2. MPA with 1 rectangular slot

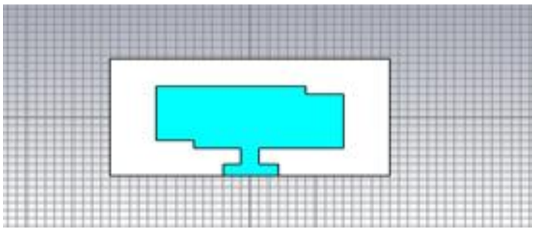

Figure 3. MPA with 2 rectangular slots

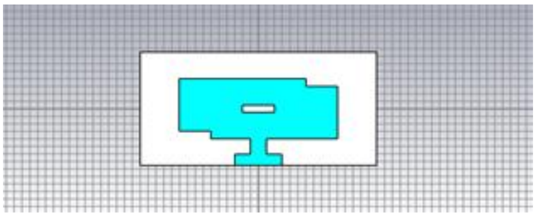

Figure 4. MPA with 3 rectangular slots

3. Results and Discussion

Standing waves occur when antenna matching is poor, resulting in the power applied to the antenna being reflected rather than emitted. Figure 5 depicts the S11 results for the various models, and Table 2 displays the values. A properly impedance matched antenna has a VSWR of 1:1. The frequency range over which an antenna can operate is referred to as its bandwidth. Figure 5 depicts the various bandwidths obtained from various designs, and the values are shown in Table 2. Figure 7 depicts a plot of VSWR for all of the models that returned a value between 1 and 2. Antenna gain is a measurement of the directivity and efficiency of an antenna. It is defined as the ratio of the peak intensity direction radiation intensity to the intensity that would be obtained if the antenna's power was radiated isotropically. Figure 8 also shows the antenna gain, and the numbers are summed and reported in Table 2. According to the results, the antenna with one slot performed better in terms of gain, directivity, and bandwidth. This demonstrates that a single slot improves antenna performance over several slots.

The narrow bandwidth and poor gain of microstrip patch antennas (MPA) are two key drawbacks. Due to their exposure to high pressure and external temperature changes, the latest wireless communication systems require operation in a variety of situations and operation bands (X band in this study). The risk of copper failure and other metal materials due to recurring bending, temperature stability, corrosion resistance, and deformations is another downside of employing a traditional copper conducting material antenna [9]. Other positive features that make graphene, as a nanomaterial, the latest trendy material in the creation of newest gadgets are that it conducts a lot of electricity in a tiny space, which allows for the development of miniaturized devices and super-fast machines that use very little power [4,8]. The use of graphene patch as a conducting material in a microstrip patch antenna is regarded to have extraordinary potential in terms of increasing antenna bandwidth and radiation efficiency due to its outstanding electromagnetic properties and functionalities. A graphene plane also provides strong shielding against microwave radiation due to its high electrical conductivity. The use of graphene as a conductive patch material has also demonstrated that it may be a viable alternative to utilizing metal conductors.

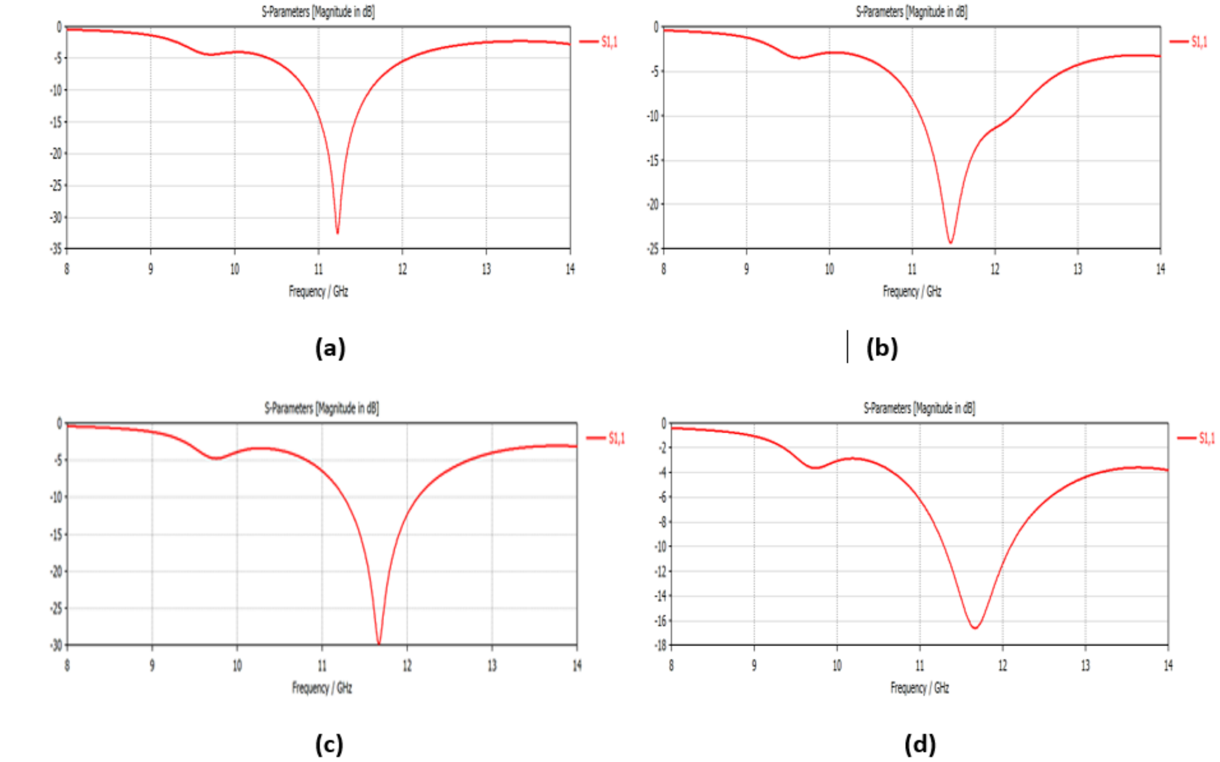

Figure 5. Bandwidth result showing (a) model 1, (b) model 2 (c) model 3 (d) model 4

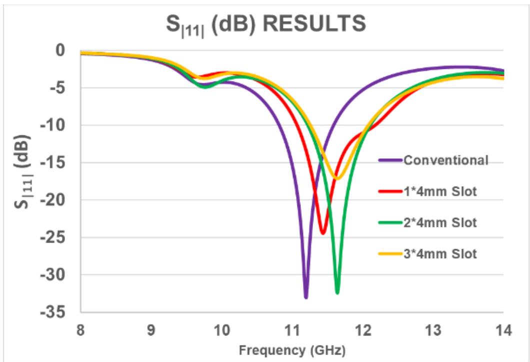

Figure 6. $S_{|11|}$ results

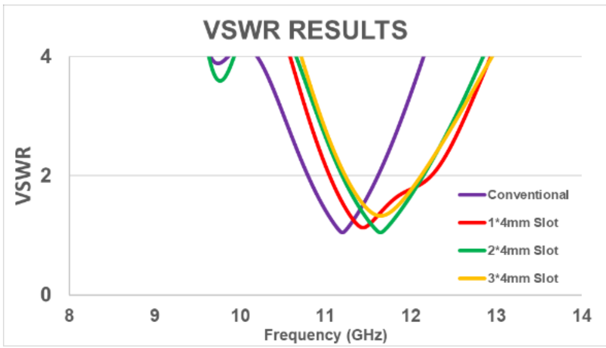

Figure 7. VSWR results

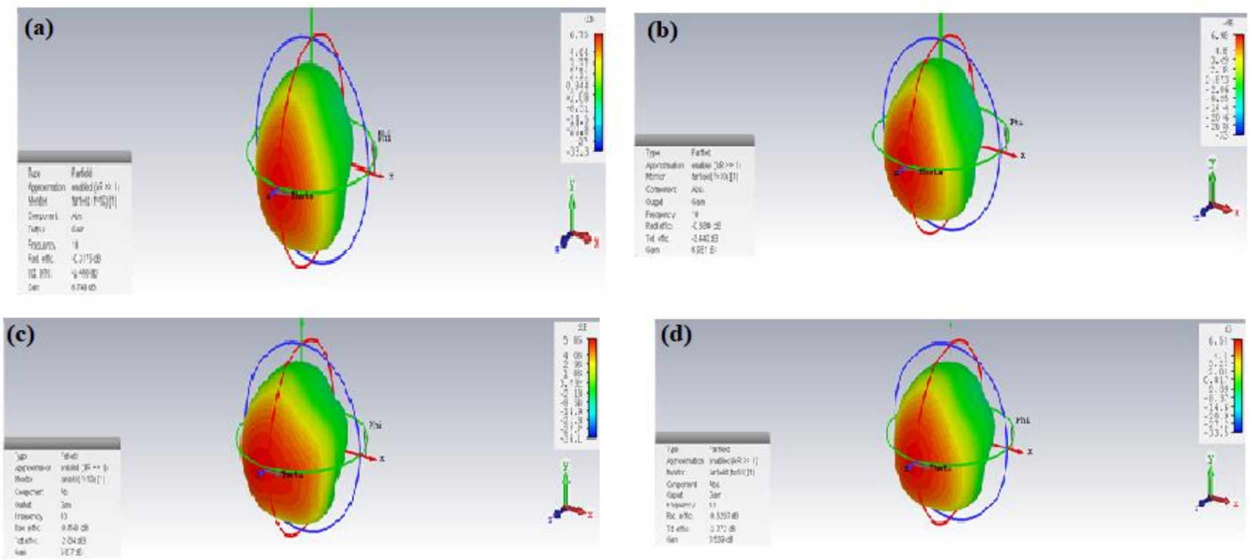

Figure 8. Gain result showing (a) model 1, (b) model 2 (c) model 3 (d) model 4

Table 2. Summary of Results

No.	Model	S11	VSWR	Rf (GHz)	Gain (Db)	Directivity (Dbi)	BW (MHz)
1	Conventional	-25.4	1.04	11.22	6.75	7.07	770
2	1mm by 4mm slot	-24.54	1.13	11.46	6.98	7.32	1114
3	2*1mm by 4mm slots	-35.56	1.03	11.69	5.86	6.17	896
4	3*1mm by 4mm slots	-16.72	1.34	11.64	6.54	6.87	814

4. Conclusion

The designed antenna performs well in terms of bandwidth and operates in the X band. The frequency ranges specified can be used for military satellites, military and government institutions for weather monitoring, air traffic control, defense and tracking vehicle speed detection for law enforcement, and the aerospace industry, where low weight, mechanical durability, and temperature independence are critical.

Compliance with Ethical Standards

There is no conflict of interest to disclose.

Conflict of Interest

The author(s) declares no known competing financial interests or personal relationships.

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