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Design and Performance Evaluation of a High Gain Compact 10GHz Inset-Fed Rectangular Microstrip Patch Antenna for Advanced Wireless Communication Systems

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A B S T R A C T

This paper presents the design and performance evaluation of a high-gain compact 10GHz inset-fed microstrip patch antenna (MPA) for advanced wireless communication systems. The antenna is designed on Rogers RT5880 substrate with a size of 30.7 x 27.9 mm2, making it suitable for compact and portable wireless devices. The antenna's reflection coefficient is -33dB, and VSWR is 1.04, indicating excellent impedance matching. The antenna's gain is 7.98dBi, and its directivity is 8.71dBi, indicating high radiation efficiency and directionality. The antenna's efficiency is 84.5 percent, indicating low power losses due to absorption or other losses. The H-field side lobe is -15.3 dB, and the E-field side lobe is -15.2 dB, indicating low sidelobe levels. The proposed antenna can be used in a wide range of advanced wireless communication systems, such as point-to-point communication, wireless sensors, and satellite communication. The simulation results show that the proposed antenna performs well in terms of radiation characteristics and can be a good candidate for various wireless communication applications.

Keywords: Rectangular Microstrip Antenna, Inset Feeding, Compact, Rogers RT 5880, High Gain

1. Introduction

Wireless communication systems have become ubiquitous in modern society, with applications ranging from personal communication devices to industrial and military systems. The design of high-performance antennas is essential to the success of these wireless communication systems. MPAs have emerged as a popular choice for wireless communication systems due to their low profile, easy integration with planar circuits, and low fabrication cost. Several techniques have been proposed to improve the performance of MPAs. Sharawi presented a design of an MPA with an inset feed and a parasitic patch to achieve a wideband response [1]. Kumar and Ray proposed a novel slot-coupled MPA with a high gain and low cross-polarization level [2]. Tawk et al. proposed a stacked MPA with a compact size and high gain for wireless communication systems [3]. This research paper proposes a high-gain compact 10GHz inset-fed MPA for advanced wireless communication systems.

The proposed antenna is designed on a substrate material that exhibits excellent high-frequency performance and low dielectric loss. The proposed antenna design is based on established MPA design principles, including the use of an inset-fed configuration and a compact patch size. The proposed antenna's performance characteristics have been analyzed using an appropriate simulation tool, including reflection coefficient, VSWR, gain, directivity, efficiency, and sidelobe levels. The simulation results demonstrate that the proposed antenna can perform well in terms of radiation characteristics, making it a promising candidate for future wireless communication applications. Also, it is designed to meet the increasing demand for high-performance wireless communication systems, including point-to-point communication, wireless sensors, and satellite communication, among others. The compact design of the antenna makes it suitable for use in portable and compact wireless devices. The antenna's performance characteristics make it a suitable alternative to existing antennas for advanced wireless communication systems.

2. Methodology

An MPA is a type of antenna used in radio communication systems that consists of a flat metallic patch placed over a ground plane and separated from it by a dielectric substrate. The patch is typically made of a conductive material, such as copper, and is designed to resonate at a specific frequency. The antenna sis fed by a coaxial cable or transmission line connected to a small section of the patch, known as the feed point [8]. The size and shape of the patch, as well as its distance from the ground plane, affect the operating frequency, gain, and radiation pattern of the antenna. MPAs are widely used due to their low profile, lightweight, and ease of integration with other electronic components. They are commonly used in mobile phones, satellite communication systems, and radar systems, among other applications. The design of an MPA at 10 GHz in Fig.1 involves several steps beginning with the

Table 1- Dimensions of mpa

Dimension	Value (mm)	Description
Lp	9.63	Patch Length
Wp	11.86	Patch Width
Ls	27.92	Substrate Length
Ws	30.70	Substrate Width
Lms	11.82	Microstrip Length
Wms	3.92	Microstrip Width
Linset	2.68	Inset Length
Winset	1.60	Inset Width

selection of the desired operating frequency. The shape and size of the patch are chosen to determine the resonant frequency, while the substrate material and thickness play a crucial role in achieving high gain and directivity [9]. The feed design, such as the microstrip feed, determines how the RF signal is applied to the patch, and the ground plane provides a reference plane for the electric field and affects the radiation pattern. The antenna design is typically simulated using CST Microwave Studio (MWS) software to optimize its performance, with the results used to adjust dimensions and parameters. Once the design is finalized, the antenna is fabricated using printed circuit board technology and tested to verify its performance using specialized equipment such as a network analyzer to measure impedance, gain, and radiation pattern.

Table 2: Selected parameters for rmpa

Parameters	Value	Description
f	10 GHz	Resonant frequency
ε_r	2.2	RT5880 Dielectric Constant
t	0.0175 mm	Patch/Ground thickness
h	1.57 mm	Substrate Height

3. Design Equation

The list of equations required for designing the MPA are:

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

In (1), W gives the practical width. Where, v_0 is the speed of light in free space, μ_0 is the permeability of free space, and ε_0 is the permittivity of free space [4].

$$L = \frac{1}{2f_r\sqrt{\epsilon_{\text{reff}}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L \quad (2)$$

$$\epsilon_{\text{reff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (3)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{\text{reff}}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{\text{reff}}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

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

$$Z_c = \begin{cases} \frac{60}{\sqrt{\epsilon_{\text{reff}}}}\ln\left[\frac{8h}{W_0}+\frac{W_0}{4h}\right], & \frac{W_0}{h} \le 1 \\ \frac{120\pi}{\sqrt{\epsilon_{\text{reff}}}\left[\frac{W_0}{h}+1.393+0.667\ln\left(\frac{W_0}{h}+1.444\right)\right]}, & \frac{W_0}{h} > 1 \end{cases} \quad (6)$$

Ls=2Lp; Ws=2Wp (7)

Here, Ls is the length of the substrate and Ws is the width of the substrate. (2) gives the actual length, (3) gives the effective dielectric, (5) gives the effective length and (6) is the relation between the characteristic impedance and width of the microstrip [5,6,7].

4. Results

This section of the research paper presents the findings of the research study and provides an objective evaluation of the results obtained. In this case, the research study was focused on the design and performance analysis of a MPA at 10 GHz. This section reports the evaluation of the antenna's performance based on several parameters, including S11, VSWR, side lobe lobe level (SLL), gain, and directivity.

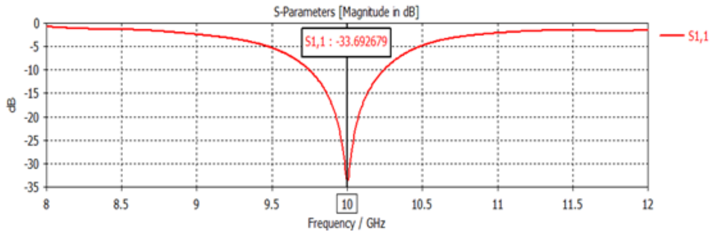


Fig. 2. S11 (dB) vs Frequency (GHz) Plot

The S11 value of -33.69 dB in Fig. 2 indicates the reflection coefficient of the antenna, which is an important parameter in determining the antenna's performance. A low S11 value indicates a good match between the antenna and the feed line, which implies that the antenna is efficient in transferring power from the feed line and radiating it into space. The VSWR value of 1.04 is also an important parameter in Fig. 3 that indicates the efficiency of power transfer between the feed line and the antenna.

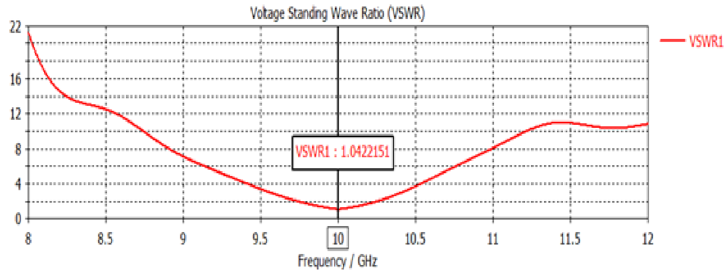
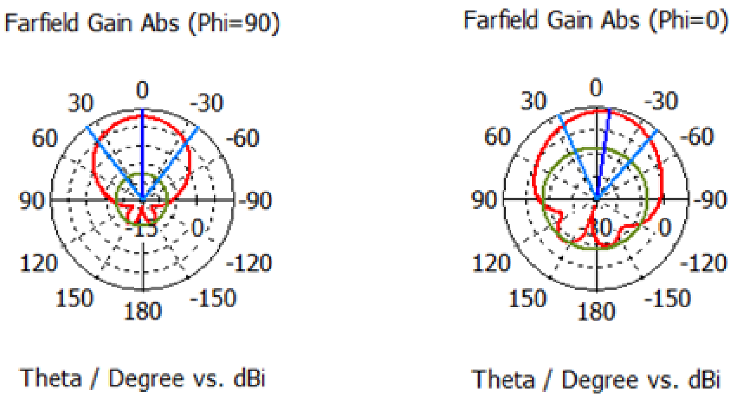


Fig. 3. VSWR vs Frequency (GHz) Plot

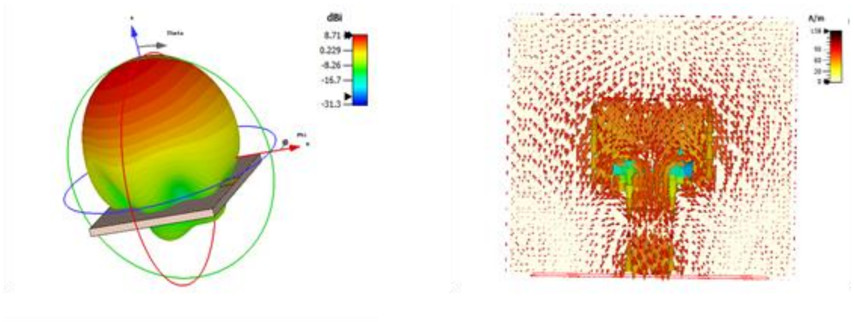
A VSWR value close to unity indicates a low level of reflection, which implies a high level of power transfer. The SLL is a measure of the antenna's ability to direct radiation in a specific direction. The H-plane and E-plane SLL values of -15.3 dB and -15.2 dB, respectively. In Fig. 4 it indicate that the antenna can direct most of its radiation in the desired direction, with minimal radiation in other directions. The gain and directivity are two important parameters that indicate the ability of the antenna to amplify and focus radiation, respectively. The gain of 7.983 dBi indicates that the antenna can amplify the signal received or transmitted. The directivity of 8.714 dBi indicates the ability of the antenna to focus its radiation in a particular direction, which is an important parameter for directional antennas used in communication systems. Overall, this section demonstrates that the designed MPA at 10GHz has excellent performance characteristics, including a good match between the antenna and the feed line, low reflection, and high power transfer. Additionally, the antenna can direct most of its radiation in the desired direction, amplify the signal, and focus the radiation in a particular direction. These results indicate that the designed MPA is a high-performing antenna suitable for a range of applications in radio communication systems.



(a) (b)

Fig. 4 (a) H-field (b) E-Field

The 3D pattern of the MPA in Fig. 5 refers to its radiation pattern in three dimensions. It is an important parameter that determines the directionality and strength of the antenna's radiation in different directions. The radiation pattern of the antenna is affected by several factors, including the size and shape of the patch, the height of the patch above the ground plane, and the feed position. The 3D pattern can be visualized using CST-MWS software that generates a graphical representation of the antenna's radiation pattern. The radiation pattern is typically displayed as a 3D polar plot, which shows the antenna's gain and radiation pattern in different directions. The 3D pattern of the designed MPA at 10 GHz is an important parameter that can be used to evaluate its performance and suitability for different applications.



(a) (b)

Fig. 5 (a) 3-D Radiation Pattern of 10GHz MPA (b) Surface Current Distribution

The current distribution of the MPA in Fig. 5 refers to the distribution of current flow on the patch and its interaction with the ground plane. The current distribution is an important parameter that affects the radiation pattern, gain, and impedance bandwidth of the antenna. The current distribution on the patch is affected by the patch geometry, substrate thickness, dielectric constant, and feed position. The interaction between the patch and the ground plane generates a current distribution typically concentrated near the patch's edges and decays towards the center [10]. The current distribution can be visualized using CST-MWS software, which visually represents the current flow on the patch. Understanding the current distribution is important for optimizing the performance of the antenna and ensuring a good impedance match with the feed line. In the case of the designed MPA at 10 GHz, the current distribution was carefully optimized to achieve high-performance characteristics, including a good impedance match, low reflection, high power transfer, and the ability to direct radiation in the desired direction.

Table 3: Comparison table

Reference	***Operating Frequency***	***Gain (dBi)***	***Substrate***
[11]	10 GHz	6.2	Rogers RT5880
[12]	10 GHz	6.58	Rogers RO4350
[13]	10 GHz	7.1	Rogers RT5880
[14]	10GHz	7.585	Rogers RT 5880
Proposed Work	10 GHz	7.98 ~ 8	Rogers RT5880

5. Conclusion

The research paper concludes that the designed MPA at 10 GHz has excellent performance characteristics, including a good impedance match, low reflection, high power transfer, and the ability to direct radiation in the desired direction, amplify the signal, and focus radiation. The design process involved the careful selection of patch shape and size, substrate material, feed design, and ground plane design, followed by rigorous simulation and testing. The results demonstrate that the designed MPA is effective in achieving high-performance characteristics, making it suitable for a wide range of applications in radio communication systems. Future work could involve further optimization of the antenna design or integration with other electronic components to enhance functionality.

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