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Performance Comparison of 10 GHz Microstrip Patch Antenna Array Using Various Substrate Materials

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Abstract: ***Microstrip patch antennas have become increasingly popular in recent years due to their simple fabrication and compatibility with modern planar circuit technologies. They are used in a wide variety of wireless communication systems such as base station terminals and mobile handset antennas. In recent years Microstrip antenna arrays have become increasingly popular due to their reliable design, lightweight, and low-cost-effective nature, making them ideal for various applications. This study presents the design and simulation of a 1×2 microstrip patch antenna array operating at 10 GHz, with an emphasis on evaluating performance across different substrate materials—FR4, Taconic RF-41, and Epoxy resin. Using CST Microwave Studio, the antenna design was optimized, and key performance indicators such as return loss, directivity, VSWR, and efficiency were analyzed. Results show that substrate material significantly influences antenna performance, with epoxy resin delivering superior efficiency and directivity. These insights can guide material selection in high-frequency communication systems.***

Keywords: array antennas, microstrip patch antenna, 10 GHz, dielectric materials, CST simulation

1. Introduction

Research into microstrip patch antenna arrays has grown in recent years as wireless communication technology continues to develop rapidly. A microstrip patch antenna is a single-layer design, usually comprised of four components (the patch, ground plane, substrate, and feed section). The advantages of microstrip antenna are: small size, Low profile, Lightweight, and Adaptable to flat and non-flat surfaces, They require a very small volume of the structure during assembly, with remarkable flexibility in their directivity and radiative characteristics for a broad range of applications, and They are simple and cheap to manufacture with modern Printed Circuit Board (PCB) technology. The disadvantages of microstrip patch antennas are: low efficiency, and narrow bandwidth of less than 5%, low radio frequency (RF) performance due to the small distance between the radiation patch and the ground plane (not suitable for high-power applications)

a) Types of microstrip patch antennas

Various shapes of microstrip patch antennas are utilized to simplify analysis and performance prediction, including square, rectangular, circular, triangular, and elliptical shapes. Among these, rectangular microstrip patch antennas are the most commonly used. The performance of a microstrip antenna is determined by factors such as substrate material, antenna dimensions, and feeding technique. To enhance gain, arrays of patch elements are often employed instead of single patches.

Moreover, microstrip patch antennas come in a variety of designs tailored to specific needs, such as those for millimeter-wave frequencies. Shapes like rectangular, square, and circular are common choices. Substrate selection plays a crucial role, impacting resonant frequency, bandwidth, and environmental factors like temperature and humidity during operation. Additionally, feeding techniques vary, including microstrip lines, coaxial probes, and coupling methods. Ensuring optimal impedance matching between the feed line and antenna input impedance is essential for maximizing power transfer and avoiding efficiency loss [1].

b) Microstrip patch antenna array

An antenna array is a network of identical antennas that are used to create a specific radiation pattern. The power output is increased due to the addition of multiple elements working together. When all of the elements are in phase, the resulting fields add together, resulting in a wide range of outcomes and capabilities. This is particularly useful in various applications.

The purpose of this study is to evaluate the influence of different substrate materials on the performance of a 1×2 microstrip patch antenna array designed to operate at 10 GHz. This investigation contributes to antenna design optimization in high-frequency domains, offering guidance for substrate material selection in practical applications such as 5G systems, satellite communications, and radar.

2. Structure and Design Specifications

a) Layer and Materials Used

A microstrip patch antenna comprises a radiating patch positioned on one side of a dielectric substrate, with a ground plane on the opposite side. The radiating patch, typically made of conducting materials like copper or gold, can assume various shapes. Manufacturing the antenna involves photoetching the patch and feed lines onto the dielectric substrate, utilizing diverse materials. Copper is commonly employed for the ground plane, patch, and microstrip line, while the substrate layer utilizes different dielectric materials [2]. The microstrip line method with a corporate-feed network model is selected as a feeding method because it is easy to fabricate and control the feeding position. The materials used in the microstrip patch antenna are listed in Table 1.

Table 1: Name of the layer and materials used

Layer name	Material name
Ground plane	Copper
Substrate	Dielectric substrate materials
Patch	Copper
Microstrip line	Copper

b) Dielectric Material Used

In this research, different dielectric materials were selected to achieve a certain cut-off frequency in order to analyze the antenna's performance. Table 2 shows the list of materials used in this research.

Table 2: List of Dielectric Materials used in this Research and their Dielectric Constants

Number	Name of the dielectric materials	Dielectric constants (εr)
1	FR4	4.3
2	Taconic RF-41	4.1
3	Epoxy resin	4

3. Design of Antenna

To calculate the patch size of the antenna operating at the targeted frequency, one must first determine three parameters: (1) resonance frequency (fo), substrate thickness (h), and dielectric constant of the substrate material (εr). This study examines the performance of a microstrip antenna using three different dielectric materials (FR-4 with a relative dielectric constant of 4.3, Taconic RF-41 with a relative dielectric constant of 4.1, Epoxy resin with a relative dielectric constant of 4), and a height of 1.575 mm was selected as the ideal substrate material and loss tangent of 0.025. The width(W) and length(L) of the patch antenna are 9.2 mm and 6.5 mm, respectively. The goal of this study is to reduce the return loss by keeping h, εr, and fo constant while optimizing other parameters.

The width of the patch can be calculated from the below equation [1][3]:

$$W = c / (2fr) * \mathrm{sqrt}(2 / (\varepsilon r + 1)) \quad (1)$$

Where:
c: speed of light in vacuum.
f: resonant frequency.
εr: dielectric constant.

Effective dielectric constant can be expressed as:

$$\varepsilon eff=(\varepsilon r+1)/2+(\varepsilon r-1)/2*[1+12(h/W)]^{\wedge}(-1/2) \quad (2)$$

Where the length correction due to fringing effects, the effective length of the patch, and the actual length of the patch after correction could be calculated from these equations (3-5):

$$\Delta L = 0.412h * [(\varepsilon eff + 0.3)(W/h + 0.264)] / [(\varepsilon eff - 0.258)(W/h + 0.8)] \quad (3)$$

$$Leff = c / (2fr * \mathrm{sqrt}(\varepsilon eff)) \quad (4)$$

$$L = Leff - 2\Delta L \quad (5)$$

The design and optimization of the 1 x 2 microstrip patch antenna array require careful selection of various geometric parameters to ensure optimal performance at the 10 GHz resonant frequency. Key dimensions such as the width, length, and locations of the patch feed points, as well as ground plane dimensions and microstrip feed lines, were calculated accurately. These dimensions are critical to achieving the desired radiation characteristics, impedance matching, and overall efficiency of the antenna array. Table 3 shows the optimal values for these dimensions and provides a detailed outline of the proposed antenna design.

Table 3: The Optimal Value of the Proposed Antenna Dimension (mm)

Parameter	w_g	w_p	w_{f1}	w_{f2}	w_{f3}
Value	35	9.5	3.7	8.4552	2.1
Parameter	l_g	l_p	l_{f1}	l_{f2}	l_{f3}
value	28	7	6	0.717	2.783
Parameter	w_{f4}	w_{f5}	w_v	h_t	l_{f4}
Value	3.6	0.6	$5*w_{f1}$	0.035	4.2
Parameter	l_{f5}	h_s			
Value	3.6	1.575			

The 1×2 microstrip patch antenna array, which consists of two patches with the same dimension mentioned in Table 3, is shown in Fig. 1.

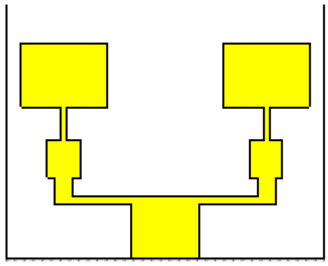

Figure 1: 1×2 microstrip patch antenna array design

4. Analysis of Simulated Results

CST Microwave Studio, featuring an array of dielectric materials, served as the primary tool for creating a microstrip patch antenna targeting a 10 GHz resonant frequency. Performance evaluation encompassed a thorough examination of each substrate's efficacy, analyzing key parameters including return loss, radiation efficiency, total efficiency, and voltage standing wave ratio (VSWR).

To determine which substrate material produced the best results, we discussed the performance of the antenna using various parameters, such as directivity and gain directivity, return loss, polarization, VSWR, and antenna gain.

- Directivity refers to an antenna's capacity to concentrate energy in a specific direction, quantified as the ratio of radiation intensity in a given direction to the average radiation intensity across all directions [4].
- Return loss plays a crucial role in assessing antennas, particularly concerning impedance matching and the principle of maximum power transfer. It acts as an indicator of how effectively the antenna transmits power from the source to itself [4].
- The orientation of the electric field vector over time characterizes polarization. This property delineates the magnitude and direction of the electric field at a specific point in space [4].
- The Voltage Standing Wave Ratio (VSWR) expresses the degree of match between the transmission line and the antenna and measures the impedance mismatch [4].

- Antenna gain represents the power achievable in a specific direction relative to the power lost in other directions and is consistently linked [4].

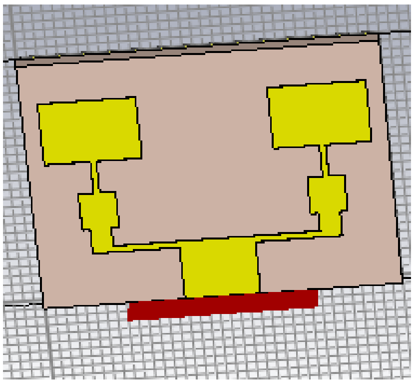

Figure 2: The final design for 1×2 microstrip patch antenna array for 10 GHz

5. Examining & Analyzing of Microstrip Patch Antenna Array using different Dielectric Materials

a) Antenna performance for FR4

Fig. 3 shows the S-parameter graph for FR4 material. The S-parameter, or reflection coefficient, measures the amount of power reflected from an antenna and is commonly referred to as the return loss. The lower the value of the S-parameter, the better the antenna's performance. In this figure, the S-parameter graph material shows that the return loss is -25.130594dB at 10 GHz, which reflects the antenna's good performance.

Fig. 4 illustrates the far field in polar view, with a half-power beam angular width of 58.6° and a side lobe level of—12.3 dB.

Fig. 5 illustrates the far field in polar view with an angular width of half power beam at 65.5° and a side lobe level of -0.9 dB.

Lastly, Fig. 6 shows the far-field region with a radiation efficiency of 0.5183 and a total efficiency of 0.5163 at 10 GHz. Moreover, the Z-axis directivity is 12.59, and radiation increases from green to red in the Z direction.

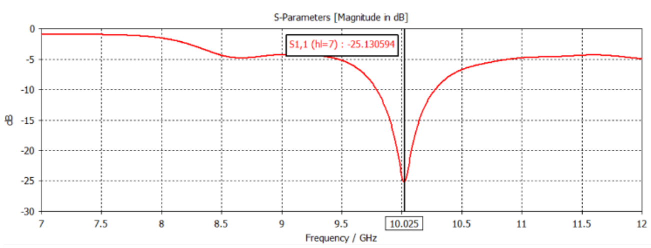

Figure 3: Return loss for FR4

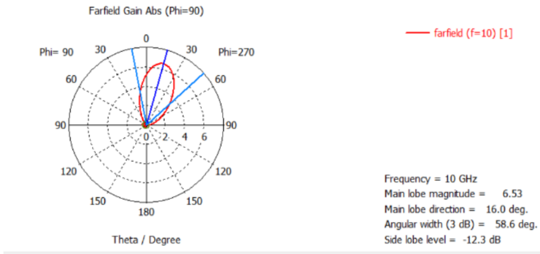

Figure 4: Far-field in polar view Phi=90 radiation pattern

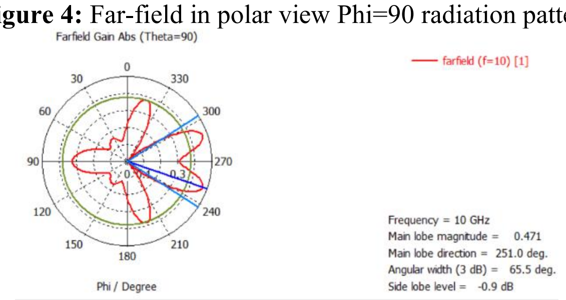

Figure 5: Theta=90 radiation pattern

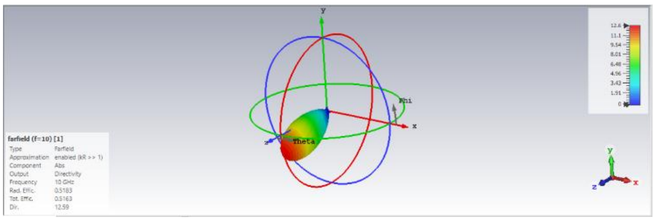

Figure 6: Fairfield of antenna

b) Antenna performance for Taconic RF-41

Fig. 7 shows the S-parameter graph for Taconic RF-41, which illustrates a better antenna performance: its reflection coefficient (or return loss) is -19.218826dB at 10GHz.

Fig. 8 illustrates the far field in polar view, with a half-power beam angular width of 60.3° and a side lobe level of—12.1 dB.

Fig. 9 illustrates the far field in polar view, with a half-power beam angular width of 62.3° and a side lobe level of -1.3 dB.

Lastly, Fig. 10 depicts the far-field region with a radiation efficiency of 0.7985 and a total efficiency of 0.6678 at 10 GHz. Moreover, the Z-axis directivity is 13.12, and radiation increases from green to red in the Z direction.

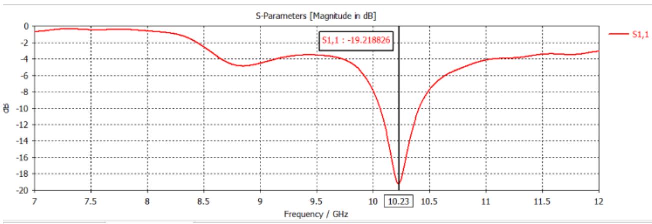

Figure 7: Return loss for Taconic RF-41

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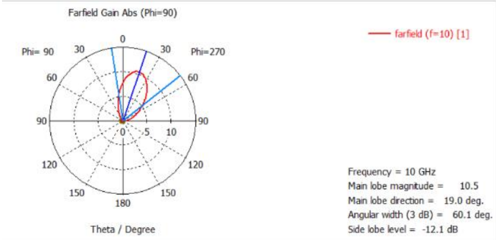

Figure 8: Far-field in polar view Phi=90 radiation pattern

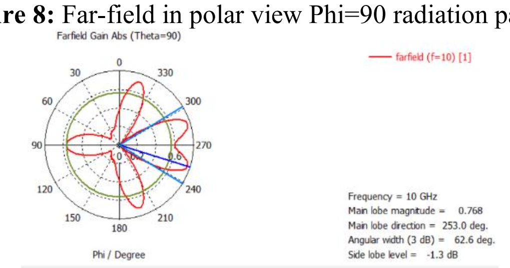

Figure 9: Theta=90 radiation pattern

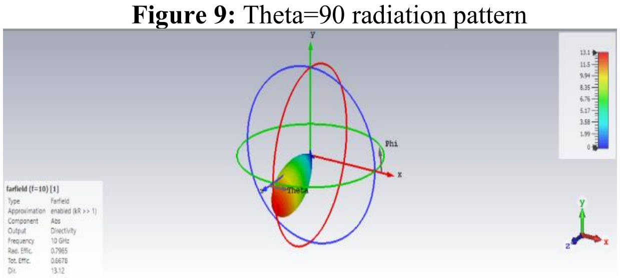

Figure 10: Fairfield of antenna

c) Antenna Performance for Epoxy resin

Fig. 11 shows the S-parameter graph for Epoxy resin, which illustrates better antenna performance: its reflection coefficient (or return loss) is -18.642776dB at 10GHz.

Fig. 12 illustrates the far field in polar view, with a half-power beam angular width of 61.4° and a side lobe level of -14.8 dB.

Fig. 13 illustrates the far field in polar view, with an angular width of a half-power beam at 60.4° and a side lobe level of -0.8 dB.

Lastly, Fig. 14 depicts the far-field region with a radiation efficiency of 0.8900 and a total efficiency of 0.8754 at 10 GHz. Moreover, the Z-axis directivity is 13.89, and radiation increases from green to red in the Z direction.

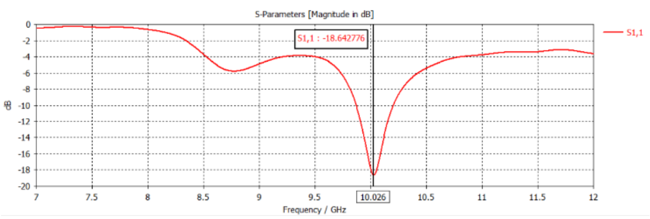

Figure 11: Return loss for Epoxy resin

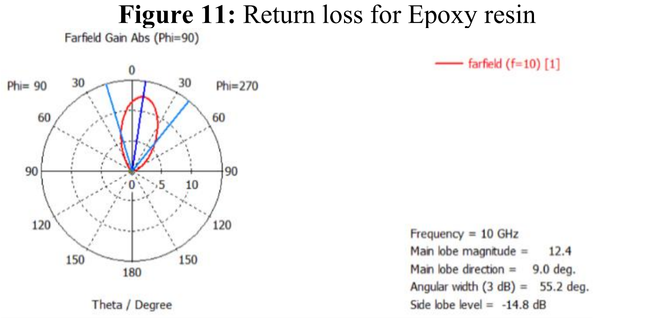

Figure 12: Far-field in polar view Phi=90 radiation pattern

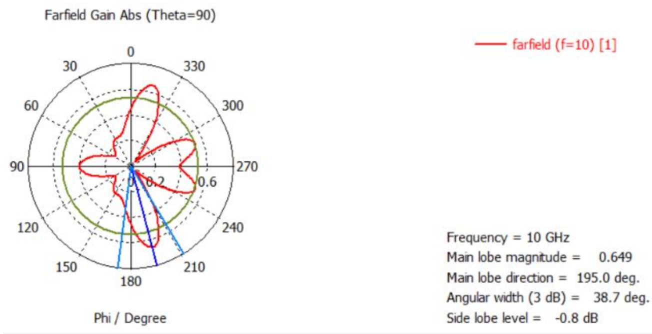

Figure 13: Theta=90 radiation pattern

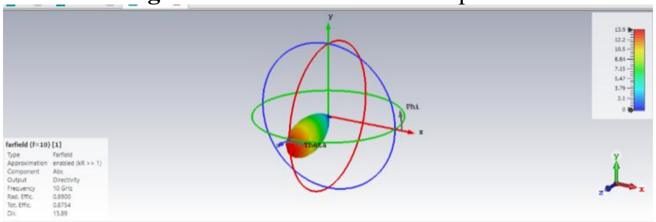

Figure 14: Fairfield of antenna

To evaluate the effectiveness of the 1 × 2 microstrip patch antenna array, simulations were performed using three different dielectric substrate materials: FR4, Taconic RF-41, and epoxy resin. The comparison focused on key performance metrics at the 10 GHz resonant frequency, including dielectric constant, return loss, sidelobe levels, VSWR, directivity, and radiation efficiency. The results provide a comprehensive assessment of the impact of each substrate on overall antenna performance, highlighting the trade-offs and benefits of each material choice. The table4 summarizes the performance parameters for each substrate material:

Table IV: Antenna Performance Comparison with Different Dielectric Materials at 10 GHz Resonant Frequency

parameters	Substrate Materials		
	FR4	Taconic RF-41	Epoxy resin
Dielec. Constant	4.3	4.1	4
Res. Freq. (GHz)	10	10	10
Return Loss (dB)	25.130594	19.218826	18.642776
Side Lobe (dB)	12.3	12.1	14.8
VSWR	1.1172871	1.2457035	1.2847814
Directivity	12.59	13.12	13.89
Radi. Effic	0.5183	0.7985	0.8900
Total Effic	0.5163	0.6678	0.8754

6. Conclusion

This study investigates the influence of substrate materials—FR4, Taconic RF-41, and epoxy resin—on the performance of a compact 1×2 microstrip patch antenna array designed for high-frequency communication systems. Key performance parameters such as return loss, VSWR, beam width, side lobe level, radiation efficiency, and total efficiency were analyzed. Among the tested materials, epoxy resin demonstrated superior performance, offering the lowest losses, narrow beam width, high Z-axis directivity, and overall efficiency. These findings provide antenna engineers with valuable insights for optimizing substrate selection in compact, high-performance antennas. Future work should explore additional dielectric materials, assess environmental effects, and integrate the antenna with multiband or wideband planar circuit technologies for broader applications.

References

[1] B. Sai Sandeep and S. Sreenath Kashyap, "Design and simulation of microstrip patch array antenna for wireless communications at 2.4 GHz," *Int. J. Sci. Eng. Res.*, vol. 3, no. 11, pp. 1–5, 2012.

[2] M. M. Islam, R. R. Hasan, and M. M. Rahman, "Design & analysis of microstrip patch antenna using different dielectric materials for WiMAX communication system," *Int. J. Recent Contrib. Eng. Sci. IT (iJES)*, vol. 4, no. 1, pp. 19–24, 2016.

[3] B. Hiçdurmaz and Ö. F. Gümüş, "Design and analysis of 28 GHz microstrip patch antenna for different type FR4 claddings," *Uludağ Univ. J. Fac. Eng.*, vol. 24, no. 2, pp. 265–288, 2019.

[4] *F. Alsager, "Design and analysis of microstrip patch antenna arrays," M.S. thesis, Univ. Coll. of Borås, Sweden, 2011.*

[5] E. K. I. Hamad and A. Abdelaziz, "Performance of a metamaterial-based 1×2 microstrip patch antenna array for wireless communications examined by characteristic mode analysis," *Radioengineering*, vol. 28, no. 4, pp. 681–687, 2019.

[6] J. Maharjan and D.-Y. Choi, "Four-element microstrip patch array antenna with corporate-series feed network for 5G communication," *Int. J. Antennas Propag.*, vol. 2020, Article ID 8816375, 2020.

[7] Y. Ipekoglu, O. M. Yucedag, S. Saraydemir, and H. Kocer, "Microstrip patch antenna array design for C-band electromagnetic fence applications," in *Proc. 9th Int. Conf. Elect. Electron. Eng. (ELECO)*, Bursa, Turkey, 2015, pp. 355-358.

[8] B. Wahab, Z. B. Maslan, et al., "Microstrip rectangular 4×1 patch array antenna at 2.5 GHz for WiMAX application," in *Proc. 2nd Int. Conf. Comput. Intell., Commun. Syst. Netw.*, 2010, pp. 164-168.

[9] C. Çakır and C. Şeker, "Design and simulation of 2.4 GHz microstrip antenna," *J. Millimeterwave Commun., Optimization and Modelling*, Feb. 2021.

[10] O. Barrou, A. El Amri, and A. Reha, "Microstrip patch antenna array and its applications: A survey," *IOSR J. Electr. Electron. Eng.*, vol. 15, no. 1, pp. 26–38, 2020.