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Analysis of the Performance of Circular Microstrip Patch Antennas with Different Dielectric Constants

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ABSTRACT

This study examines the performance of circular microstrip patch antennas with varying dielectric constants, focusing on their characteristics such as resonant frequency, and gain. The research evaluates the impact of various dielectric constants on antenna performance, providing insights for optimal design. The study found that the antenna performed well on 12 GHz frequency due to fringing fields along the edges. The study compares return loss and gain for various dielectric constants, suggesting that an optimal balance between miniaturization and performance can be achieved by carefully selecting the dielectric substrate. The research provides practical guidelines for designing efficient microstrip patch antennas for specific applications like wireless communication, radar systems, and satellite technology, where the choice of dielectric material is crucial for achieving desired performance.

Keywords : Microstrip Patch Antenna, Dielectric Substrate, Dielectric Constant, CST.

I. INTRODUCTION

Microstrip patch antennas, particularly circular microstrip patch antennas (CMPAs), are popular in modern communication systems due to their low profile, lightweight design, and ease of integration. CMPAs are particularly useful for applications requiring polarization diversity. However, the performance of CMPAs is significantly influenced by the choice of dielectric substrate. The dielectric constant (Ɛr) of the substrate directly affects critical parameters like resonant frequency and gain [1] . This research aims to analyze the performance of CMPAs with varying dielectric constants using simulations using CST software. Key metrics such as return loss and gain are compared for antennas with different dielectric constants. The analysis will provide insights into optimizing trade-offs between antenna size and performance, guiding the design of CMPAs for various applications. The research aims to contribute to the development of more efficient antennas by understanding the role of dielectric constants in antenna design [2].

II. Characteristics of Dielectric Substrates:

Dielectric substrates play a crucial role in determining the performance of microstrip patch antennas. Various materials exhibit different electrical, thermal, and mechanical properties, making them suitable for specific frequency ranges and applications [3]. Below is a comparison of the key characteristics of FR4, RO4003C, Taconic TLC-32, RT Duroid 5880, and PTFE dielectric substrates:

2.1 FR4

FR4 is a popular dielectric material in printed circuit boards (PCBs) due to its affordability and performance. It is a glass-reinforced epoxy laminate with good mechanical strength, electrical insulation, and moderate thermal resistance. With a dielectric constant around (4.4) and high loss tangent, FR4 is suitable for low-frequency applications and is resistant to moisture and environmental factors. Although not ideal for high-frequency or RF applications due to higher signal loss, FR4 remains popular in general electronics and PCB manufacturing.

2.2 RO4003C

RO4003C is a high-frequency laminate developed by Rogers Corporation for RF and microwave applications. Its low dielectric constant (3.55) and low loss tangent make it ideal for high-frequency circuits. Composed of a ceramic-filled hydrocarbon resin system, it offers superior electrical performance and is compatible with standard PCB manufacturing processes. It is a popular choice for applications like antennas, amplifiers, and RF components requiring reliable signal integrity.

2.3 Taconic TLC-32

Taconic TLC-32 is a high-performance low-loss dielectric material used in microwave and RF applications, particularly in PCB production. Its excellent thermal stability, low dielectric constant (3.2), and low dissipation factor make it suitable for various environmental conditions. Its superior mechanical strength and dimensional stability ensure reliability in precision applications. Taconic TLC-32 is compatible with standard PCB fabrication processes, making it easy to integrate into existing manufacturing workflows.

2.4 RT Duroid 5880

RT Duroid 5880 is a high-performance dielectric material used in microwave and RF applications due to its low dielectric constant (2.2) and low loss tangent. It is ideal for high-frequency circuits, offering minimal signal loss and consistent performance. Its excellent thermal and mechanical stability make it suitable for harsh environments like aerospace and defense. Its lightweight and easy-to-fabricate nature make it a preferred choice for advanced antenna designs and radar systems.

2.5 PTFE

Polytetrafluoroethylene (PTFE) is a versatile dielectric material with excellent electrical and mechanical properties. It is ideal for high-frequency and microwave applications due to its low dielectric constant (2.1) and low loss tangent. PTFE also exhibits exceptional chemical resistance, thermal stability, and can operate in extreme temperatures. It is non-reactive and has low moisture absorption, making it a preferred material in RF applications, including printed circuit boards and antennas.

Table 1 . Characteristics of different dielectric substance

Property	FR4	RO4003C	Taconic TLC-32	RT Duroid 5880	PTFE
Dielectric Constant (εr)	4.4	3.38	3.2	2.2	2.1
Loss Tangent (tan δ)	0.015 - 0.02	0.0027	0.003	0.0009 - 0.0021	0.0002 - 0.001
Frequency Range	Low to mid-range (up to ~3 GHz)	High frequencies (up to ~10 GHz)	High frequencies (up to ~18 GHz)	High frequencies (up to ~40 GHz)	High frequencies (up to ~50 GHz)
Thermal Stability	Moderate	Good	Good	Excellent	Excellent
Cost	Low	Moderate	Moderate	High	High
Mechanical Strength	High	Moderate	High	Moderate	Low
Moisture Absorption	High	Low	Low	Very low	Very low
Thermal Conductivity	Low	Moderate	Moderate	High	High

Table 1. gives the selection of a dielectric material depends on the specific requirements of the application. FR4 is a cost-effective option for low-frequency, low-cost designs but may not perform well at higher frequencies or in extreme environments. RO4003C and Taconic TLC-32 offer a good balance of performance and cost for high-frequency applications, with better thermal stability and lower signal loss than FR4. RT Duroid 5880 and PTFE are premium materials, providing excellent performance in ultra-high-frequency applications, superior thermal stability, low signal loss, and high thermal conductivity, but they come at a higher cost. Each material has its strengths and limitations, making them suitable for different design scenarios based on frequency, cost, environmental factors, and mechanical or thermal requirements [4-5].

III. Methodology

The performance analysis of circular microstrip patch antennas with varying dielectric constants follows a structured methodology. First, the antennas are designed and simulated using CST Microwave Studio, starting with a baseline model featuring standard dimensions and a known dielectric permittivity. The dielectric constant is then varied, typically from 2.1 to 4.4, to evaluate its effect on key metrics like resonant frequency, bandwidth, gain, and radiation patterns. Simulations and experimental measurements, conducted in an anechoic chamber using tools such as a network analyzer, compare results and validate trends, offering insights for optimizing antenna designs for specific applications [6].

IV. Circular microstrip Antenna Design

This research paper focuses on the design and performance analysis of a circular microstrip patch antenna resonating at 12 GHz, employing various dielectric substrates. The primary objective is to investigate how different substrate materials with varying dielectric constants affect key performance parameters such as bandwidth, gain, resonant frequency, and radiation pattern. The antenna design process involves simulation using electromagnetic software to optimize the feed position, substrate thickness, and patch dimensions [7].

The dimensions of the circular microstrip patch antenna is to be calculated using following given formula

$$a = \frac{F}{\left\{1+\frac{2h}{\pi \varepsilon r F}\left[In\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \quad (1)$$

$$a_e = a\left\{1 + \frac{2h}{\pi \varepsilon r F}\left[In\left(\frac{\pi F}{2h}\right) + 1.7726\right]^{1/2}\right\} \quad (2)$$

$$(f_r)_{110} = \frac{1.8412 v_o}{2\pi a_e \sqrt{\varepsilon r}} \quad (3)$$

Where:

a = Physical radius of the patch

a_e = effective radius

f_r = Resonant frequency of circular patch antenna

ε_r = Substrate relative permittivity

h = substrate height

Table 2. Antenna Design specification

Parameter	Value
Operating Frequency	12 GHz
Patch Radius	7.69mm
Substrate dimension	20 X 20 X 1.2 mm (L X W X h)
Substrate material (dielectric constant)	FR4 – 4.4 RO4003C – 3.55 Taconic TLC-32 – 3.2 RT-Duroid 5880 – 2.2 PTFE – 2.1
Ground plane	20 X 20 mm (L X W)
Feeding technique	Coaxial Feeding

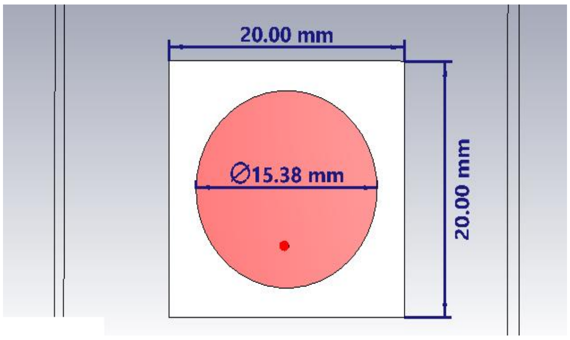

Fig. 1: Proposed Circular MPA with Coaxial Feeding Technique

V. Simulation Results using different dielectric material

The purpose of this research is to systematically analyze the performance of circular microstrip patch antennas with varying dielectric constants [8]. By conducting simulations using CST software, antennas designed with different substrate materials are evaluated to determine how changes in dielectric constant influence their performance is as given below.

5.1 FR4:

Fig. 2 shows the return loss of Circular shape microstrip patch antenna with FR4 substrate with 4.4 dielectric constant exhibits a return losses of -25.42dB for 8.78 GHz and -39.48 dB for 14.83GHz frequency respectively.

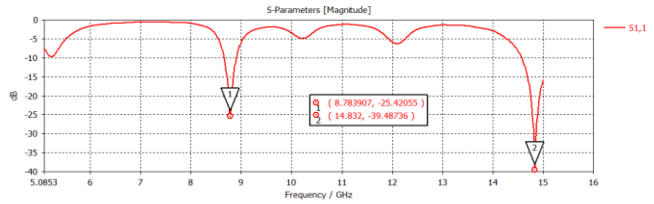

Fig.2 Return Loss vs frequency on FR4

5.2 RO4003C:

Fig. 3 shows the return loss of Circular shape microstrip patch antenna with RO4003C substrate with 3.55 dielectric constant exhibits a return losses of -10.50dB for 9.61 GHz.

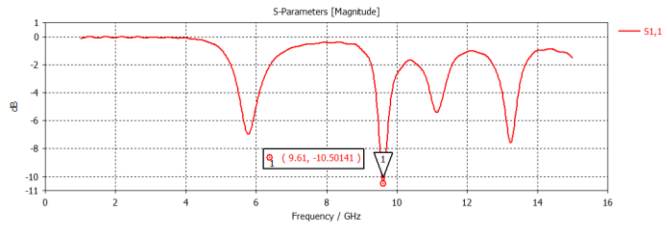

Fig.3 Return Loss vs frequency on RO4003C

5.3 Taconic TLC32:

Fig. 4 shows the return loss of Circular shape microstrip patch antenna with RO4003C substrate with 3.2 dielectric constant exhibits a return losses of -13.26dB for 10.08 GHz.

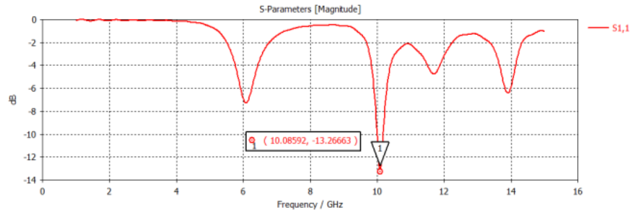

Fig.4 Return Loss vs frequency on Taconic TLC-32

5.4 RT duroid 5880

Fig. 5 shows the return loss of Circular shape microstrip patch antenna with RO4003C substrate with 2.2 dielectric constant exhibits a return losses of -47.68dB for 12 GHz.

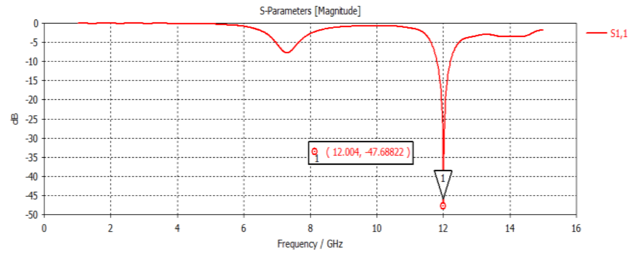

Fig.5 Return Loss vs frequency on Taconic TLC-32

5.5 PTFE

Fig. 6 shows the return loss of Circular shape microstrip patch antenna with RO4003C substrate with 2.1 dielectric constant exhibits a return losses of -34.14dB for 12.27 GHz.

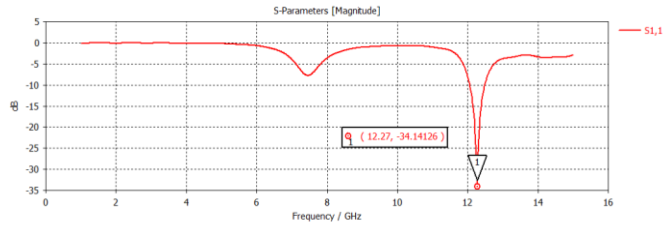

Fig.6 Return Loss vs frequency on PTFE

Table 3. Comparison of the Circular Shape Microstrip Patch Antennas with Different Dielectric Constant

Sr. No.	Dielectric Constant	Frequency (GHz)	S11 (dB)	VSWR	Gain
1	FR4 - 4.4	8.78	-25.42	1.11	1.14
		14.83	-39.48	1.02	4.90
2	RO4003C – 3.55	9.61	-10.50	1.85	3.67
3	Taconic TLC 32 –	10.08	-13.26	1.55	4.14

	3.2				
4	RT Duroid 5880 – 2.2	12	-47.69	1.00	5.95
5	PTFE – 2.1	12.27	-34.14	1.04	6.12

VI. CONCLUSION

The assessment of the results and the The comparative study of circular microstrip patch antennas using different dielectric constants highlights the impact of substrate material on antenna performance. FR4 (Ɛr = 4.4) exhibits good return loss and VSWR at 8.78 GHz and 14.83 GHz, but lower gain compared to other materials. RO4003C (Ɛr = 3.55) and Taconic TLC-32 (Ɛr = 3.2) show moderate performance, with better gain than FR4 but higher VSWR. RT Duroid 5880 (Ɛr = 2.2) achieves the best performance at 12 GHz, with the lowest S11 and perfect VSWR (1.00), while PTFE (Ɛr = 2.1) at 12.27 GHz offers the highest gain (6.12 dB), demonstrating its superiority for high-frequency applications.

VII. REFERENCES

[1]. Zhang H, Dong Y, Cheng J, Hossain MJ, Leung VCM, “Fronthauling for 5G LTE-U ultra dense cloud small cell networks,” IEEE Wireless Communication 2016. vol. 23(6), pp 48-53.

[2]. S. Path, “A Straight Path Towards 5G,” Straight Path Communications Inc, 2015, pp. 1–29.

[3]. Olga Boric-Lubecke, Victor M. Lubecke, Branka Jokanovic, Aditya Singh, Ehsaneh Shahhaidar, and Bryson Padasdao, “Microwave and Wearable Technologies for 5G”, 12th International Conference on Tele-communication in Modern Satellite, Cable and Broadcasting Services (TELSIKS), 14-17 October 2015.

[4]. Naveen Kumar, " Anomaly Detection in ERP Systems Using AI and Machine Learning, International Journal of Scientific Research in Science, Engineering and Technology(IJSRSET), Print ISSN : 2395-1990, Online ISSN : 2394-4099, Volume 6, Issue 3, pp.522-530, May-June-2019. Available at doi : https://doi.org/10.32628/IJSRSET19115110

[5]. Rajveer S Yaduvanshi, Harish Parthasarathy and Asok De, “Magneto-Hydrodynamic Antenna Design and Development Analysis with proto-type,” International Journal of Advanced Computer Science and Applications (IJACSA), Vol. 2, No.2, February 2011.

[6]. H. Sajjad, W. T. Sethi, K. Zeb and A. Mairaj, “Microstrip patch antenna array at 3.8 GHz for WiMax and UAV applications,” 2014 International Workshop on Antenna Technology: Small Antennas, Novel EM Structures and Materials, and Applications (iWAT), Sydney, NSW. pp. 107-110.

[7]. K. T. Pakkiam, J. S. Mandeep and M. T. Islam, “Design of microstrip antenna for modern wireless communication,” International Symposium on Telecommunication Technologies, Kuala Lumpur, 2012, pp. 42-46.

[8]. C. A. Balanis, “Antenna theory: a review,” Proc. IEEE, vol. 80, no. 1,1992, pp. 7–23.

[9]. Kiran, K., & Popalghat, S. K. Review and Survey of Arbitrary Shape Dual Frequency and Dual Polarized Microstrip Patch Antenna. International Journal on Recent and Innovation Trends in Computing and Communication, 4(4), 648-652.

[10]. Kataria, B., Jethva, H.B., Shinde, P.V., Banait, S.S., Shaikh, F., Ajani, S. (2023). SLDEB: Design of a secure and lightweight dynamic encryption bio-inspired model for IoT networks. International Journal of Safety and Security Engineering, Vol. 13, No. 2, pp. 325-331. https://doi.org/10.18280/ijsse.130214