International Journal of Scientific Research in Modern Science and Technology
ISSN: 2583 -7605 (Online)
© IJSRMST | Vol. 4 | Issue 6 | June 2025
Available online at: https://ijsrmst.com/
DOI: https://doi.org/10.59828/ijsrmst.v4i6.330

Design and Analysis of a Microstrip Patch Antenna Operating at 38 GHz

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Abstract:

This project focuses on the design of a **Rectangular microstrip patch antenna (RMPA)** optimized for operation at **38 GHz**. Two different substrate materials—**FR4 Epoxy** and **RT Duroid 5880**—are evaluated to compare their influence on the antenna's performance. The antenna is initially developed as a simple patch and later enhanced by incorporating a **Defected Ground Structure (DGS)**. Simulations are carried out using **HFSS software** to analyze key parameters such as **return loss, gain, bandwidth**, and **VSWR**. The findings indicate that **RT Duroid 5880** outperforms FR4, offering **higher gain** and a **broader bandwidth**. Additionally, the implementation of **DGS** significantly boosts the antenna's performance by improving gain and impedance matching. This design is well-suited for **high-frequency applications**, including **5G communication** and **radar systems**

Keywords: Rectangular microstrip patch antenna, FR4 Epoxy, RT Duroid 5880, Defected Ground Structure (DGS).

1. Introduction

With the rapid advancement of wireless communication technologies, there is a growing demand for **compact, high-frequency antennas**. Among the many types of antennas, **microstrip patch antennas** have become highly popular due to their **low profile, lightweight design, ease of manufacturing**, and **integration capability with circuit components**. These features make them especially suitable for **modern communication systems**, particularly in the **millimeter-wave (mmWave) frequency range**.

This project involves the **design and analysis of a rectangular microstrip patch antenna (RMPA)** operating at **38 GHz**, utilizing two different substrate materials: **FR4 Epoxy** and **RT Duroid 5880**. Initially, basic patch antennas are developed for both substrates, followed by enhancements using a **Defected Ground Structure (DGS)** to improve performance.

The primary objective is to investigate how the choice of **substrate material** and the inclusion of **DGS** influence critical performance parameters such as **return loss, gain, VSWR**, and **bandwidth**. All antenna designs and simulations are conducted using **HFSS software**, enabling accurate evaluation of the antenna characteristics.

2. ANTENNA CONFIGURATION

A **conventional rectangular microstrip patch antenna** using a **quarter-wave transformer feed** is designed to operate at **38 GHz**. The antenna is modeled and simulated using **HFSS software**. The structure includes a **copper patch** placed on a **RT Duroid 5880 substrate** with a **dielectric constant of 2.2** and a **thickness of 1.6 mm**. The **ground plane** measures **6.2 mm in length** and **7.4 mm in width**. To achieve proper impedance matching, a **quarter-wave transformer technique** is employed in the feedline design.

For comparison, a similar antenna is also developed using an **FR4 epoxy substrate** with a **dielectric constant of 4.4** and the same **thickness of 1.6 mm**. The **patch dimensions** for both substrates are computed using standard design equations to ensure resonance at **38 GHz**.Subsequently, both antenna designs are enhanced by implementing a **Defected Ground Structure (DGS)** in the ground plane to improve key performance parameters such as **return loss, gain**, and **bandwidth**. All simulations are carried out in **HFSS** to examine the effects of **substrate material** and **DGS** on overall antenna performance.

- Performance Metrics of Rectangular Microstrip Patch Antenna Using FR4 Epoxy Substrate

Substrate (mm)	S11(return loss)		F0(resonating frequency) GHz		Gain (dB)	B.W	XP		VSWR
							+ϴ	-ϴ	
1.6	-10	-19	17.1750	28.6500	5.2281	0.225	-12	-13	5.6034

Table 1: Performance Metrics of Rectangular Microstrip Patch Antenna Using FR4 Epoxy Substrate

The antenna designed using an **FR4 Epoxy substrate** exhibits dual resonance, with return loss values of **-10 dB** and **-19 dB** at resonant frequencies of **17.1750 GHz** and **28.6500 GHz**, respectively. The antenna achieves a gain of approximately **5.23 dB** and a relatively narrow bandwidth of about **0.225 GHz**. The cross-polarization levels are measured at **-12 dB** and **-13 dB**, indicating moderate polarization purity. However, the Voltage Standing Wave Ratio (**VSWR**) is relatively high at **5.60**, suggesting impedance matching could be improved.

Performance Parameters of RMPA with Defected Ground Structure (DGS) on FR4 Epoxy Substrate at 38 GHz

Substrate (mm)	Radius (mm)	S11(return loss)		F0(resonating frequency) GHz		Gain (dB)	B.W	XP		VSWR
								+ϴ	-ϴ	
1.6	1.4	-6	-38	17.3250	39.0750	4.9268	3.15	-13	-12	10.0131

Table 2: Performance Parameters of RMPA with Defected Ground Structure (DGS) on FR4 Epoxy Substrate at 38 GHz

The table shows the results of the antenna using FR4 epoxy with a 1.4mm radius DGS slot. the antenna gives two resonating frequencies at 17.3250GHz and 39.0750GHz. the return loss is good, especially at 39GHz with -38db, showing strong signal performance. The gain is 4.9268db, and the bandwidth is improved to 3.15GHz. the cross-polarization values are acceptable.

Performance parameters of RMPA with RT Duroid 5880 substrate basic patch at 38GHz

Substrate (RT Duroid 5880) (mm)	S11(return loss)		F0(resonating frequency) GHz		Gain (dB)	B.W	XP		VSWR
							+ϴ	-ϴ	
1.6	-13	-12	24.2250	39.4500	6.7935	1.275	-3	-4	3.8646

Table 3: performance parameters of RMPA with RT Duroid 5880

The antenna designed with RT Duroid 5880 substrate shows two return loss values of -13db and -12db, with resonating frequencies at 24.2250GHz and 39.4500GHz, indicating dual resonance behavior. The antenna achieves a higher gain of 6.7935db and bandwidth is 1.275GHz, which is significantly wider. The cross-polarization values are -3db and -4db and the VSWR is 3.8646, which is better.

Performance parameters of RMPA with DGS Using RT Duroid 5880 substrate basic patch at 38GHz

RADIUS (mm)	S11(return loss)		F0(resonating frequency) GHz		GAIN (dB)	B. W	XP		VSWR
							+ ϴ	- ϴ	
2.0	-20	-11	22.57	38.10	6.7083	2.1	-4	-5	1.8310
1.8	-16	-11	22.80	38.47	7.0519	1.725	-3	-5	2.8587
1.6	-14	-12	23.10	38.77	7.1062	1.575	-4	-4	3.4888
1.4	-13	-12	22.40	39.07	7.1002	1.35	-3	-4	3.9761
1.2	-13	-12	23.70	39.30	6.9718	1.275	-3	-4	4.0323
1.0	-12	-12	23.85	39.22	6.8766	1.125	-3	-4	4.3213
0.8	-13	-12	24.00	39.37	6.9601	1.275	-3	-4	3.9785
0.4	-13	-13	24.00	39.22	6.9561	1.2	-4	-5	4.1629
0.2	-13	-12	24.15	39.45	6.9650	1.2	-4	-5	4.0310
0.8	-13	-12	24.00	39.37	6.9601	1.275	-3	-4	3.9785
0.4	-13	-13	24.00	39.22	6.9561	1.2	-4	-5	4.1629
0.2	-13	-12	24.15	39.45	6.9650	1.2	-4	-5	4.0310

Table 4: performance parameters of RMPA with DGS using RT Duroid 5880

The table presents the performance characteristics of a rectangular microstrip patch antenna (RMPA) fabricated on an RT Duroid 5880 substrate with a defected ground structure (DGS). The radius of the circular slot in the DGS is varied from 0.2 mm up to 2.0 mm. As the radius increases, the antenna demonstrates improved performance in return loss, bandwidth, and gain. At a radius of 2.0 mm, the return loss reaches a maximum of -20 dB, indicating strong resonance and minimal signal reflection. This radius also corresponds to the widest bandwidth measured at 2.1 GHz, and the gain at this point is 6.7083 dB. Another notable result occurs at a radius of 1.8 mm, where the antenna achieves a peak gain of 7.0519 dB. While the resonant frequencies exhibit slight shifts across different radii, they consistently remain centered near the target frequency of 38 GHz. The lowest VSWR values occur at the larger radii, suggesting improved impedance matching. Overall, the introduction of the DGS effectively enhances both gain and bandwidth while maintaining cross-polarization within acceptable limits. This demonstrates that careful adjustment of the DGS circular slot radius can significantly boost antenna performance.

3 RESULTS AND DISCUSSION

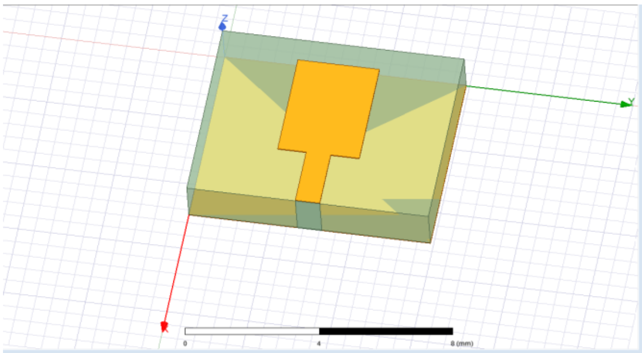


Fig1(a): performance parameters of RMPA with FR4 epoxy

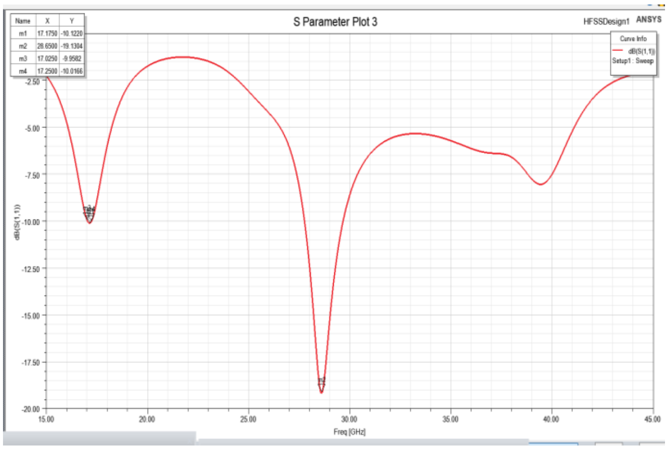


Fig 2 (a): Return loss for FR4 epoxy

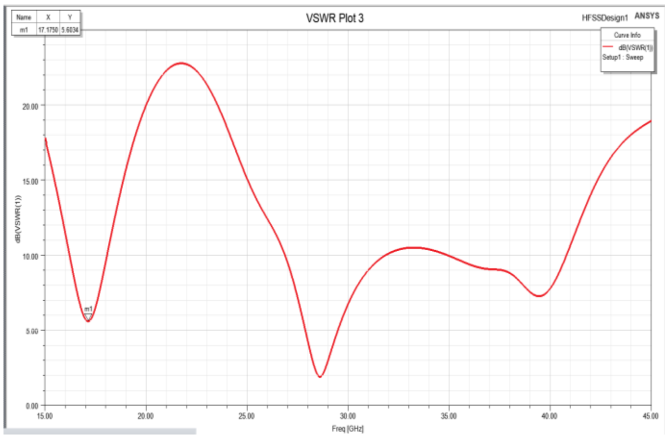


Fig 2 (b): VSWR for FR4 epoxy

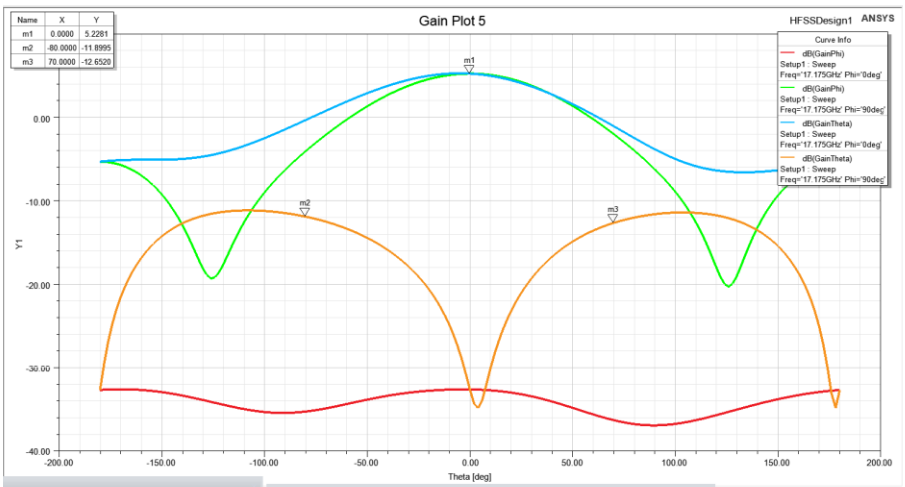


Fig 2 (c): Gain plots for FR4 epoxy

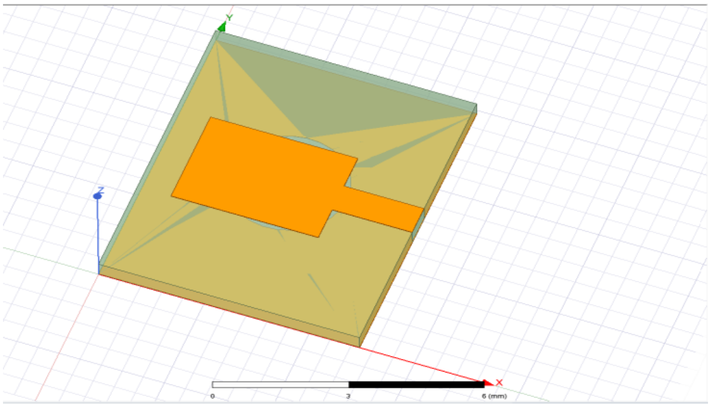
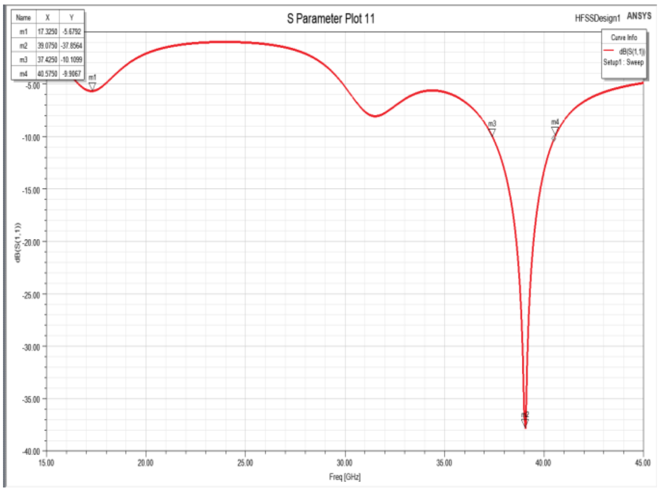


Fig3(a): performance parameters of RMPA with DGS using FR4 epoxy



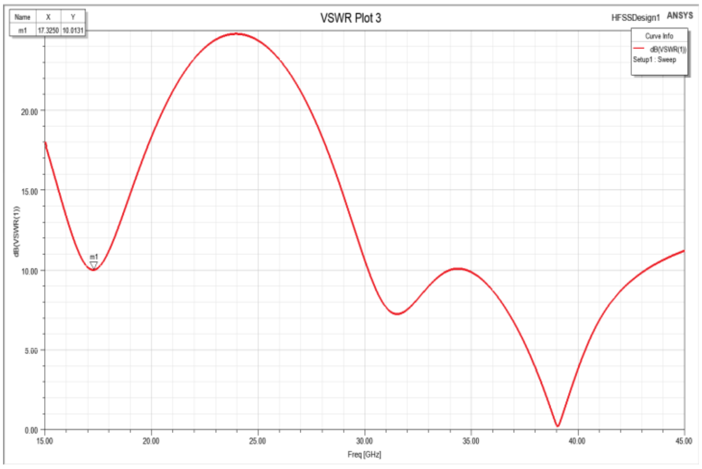
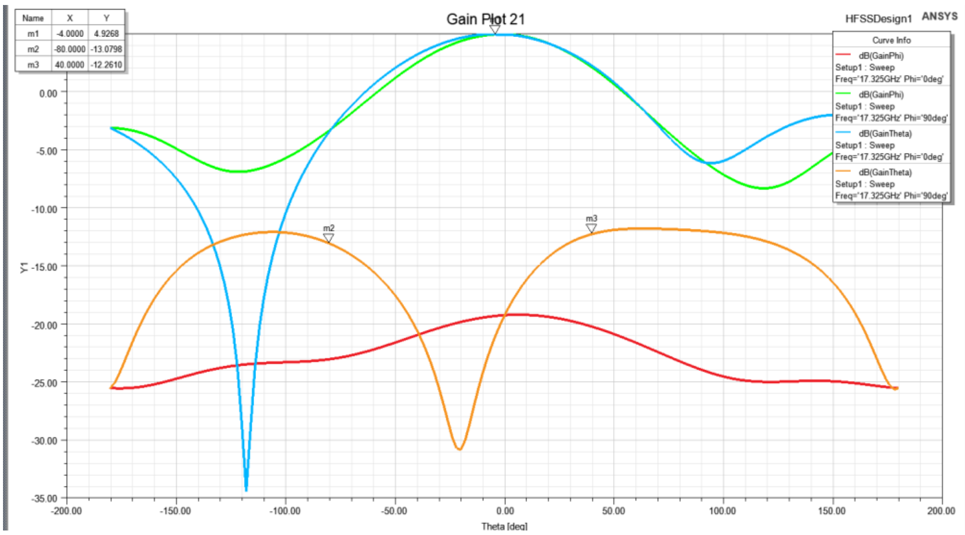


Fig 4 (a): Return loss for DGS using FR4 epoxy

Fig 4 (b): VSWR for DGS using FR4 epoxy



4 (c): Gain plots for FR4 epoxy

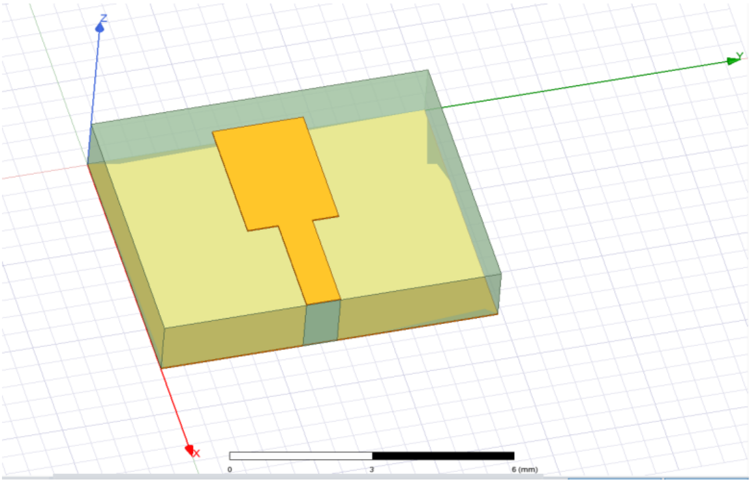


Fig5(a): performance parameters of RMPA with RT Duroid 5880

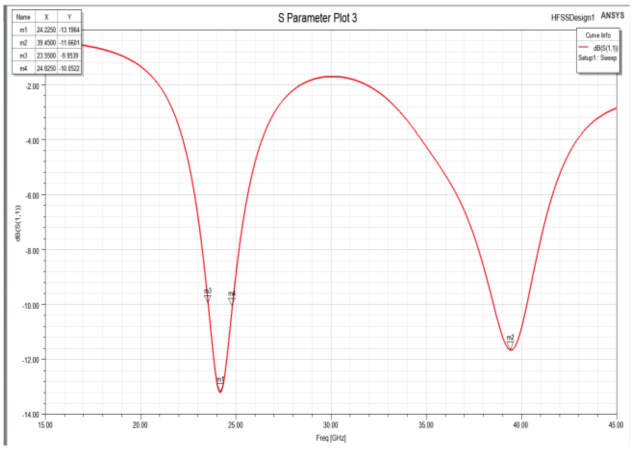


Fig 5(b): return loss for RT Duroid

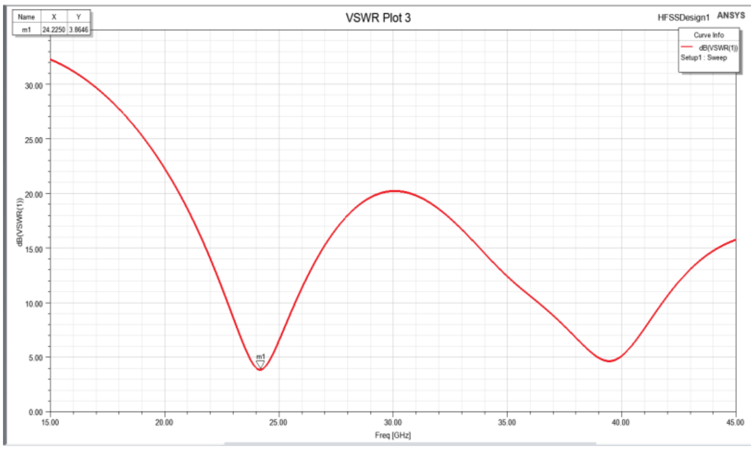


Fig 5(c): VSWR for RT Duroid

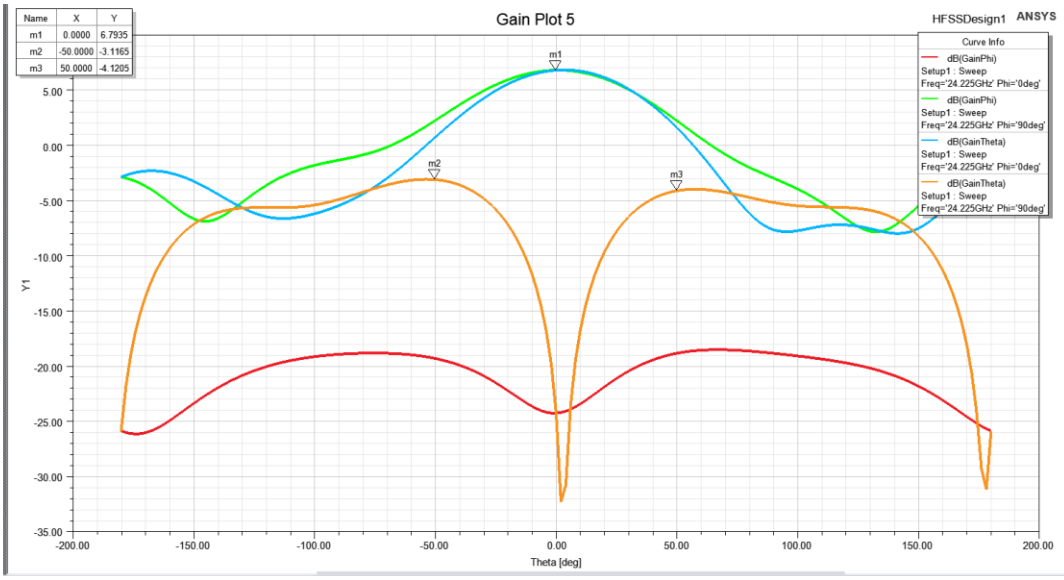


Fig 5(d): Gain plots for RT Duroid

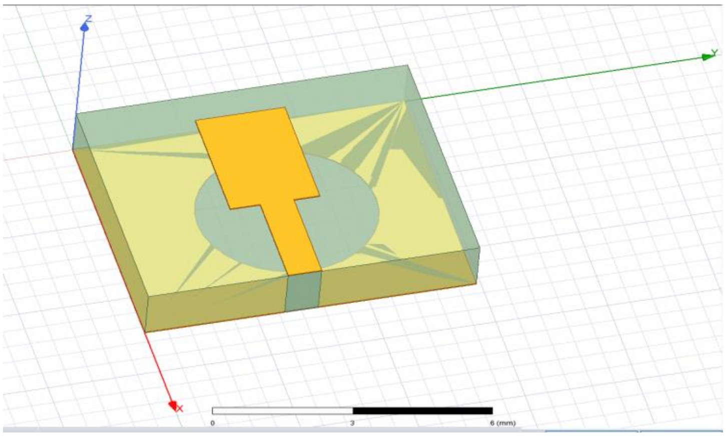
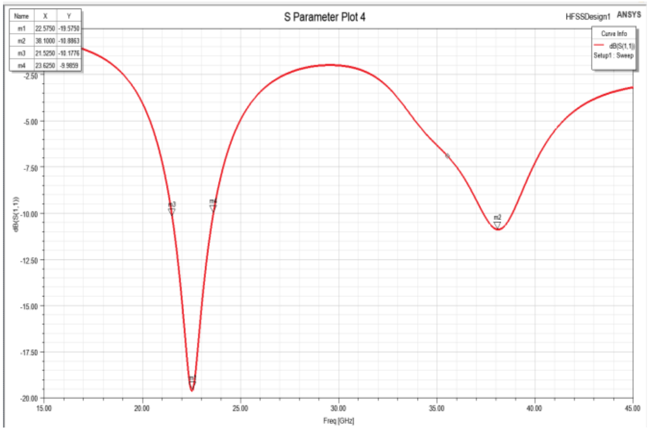


Fig 6(a): RMPA with DGS for RT Duroid



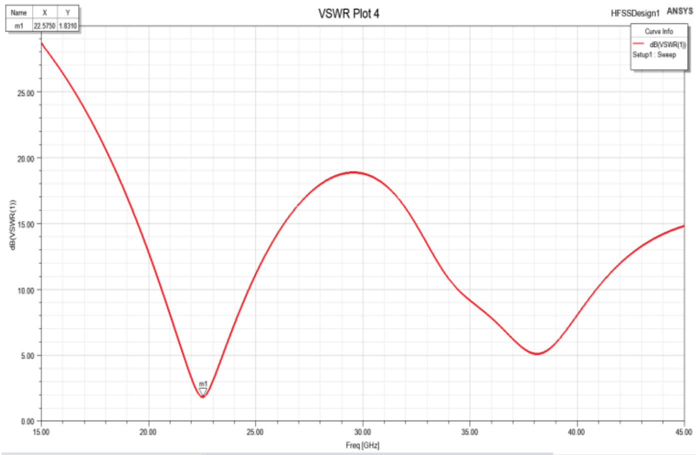
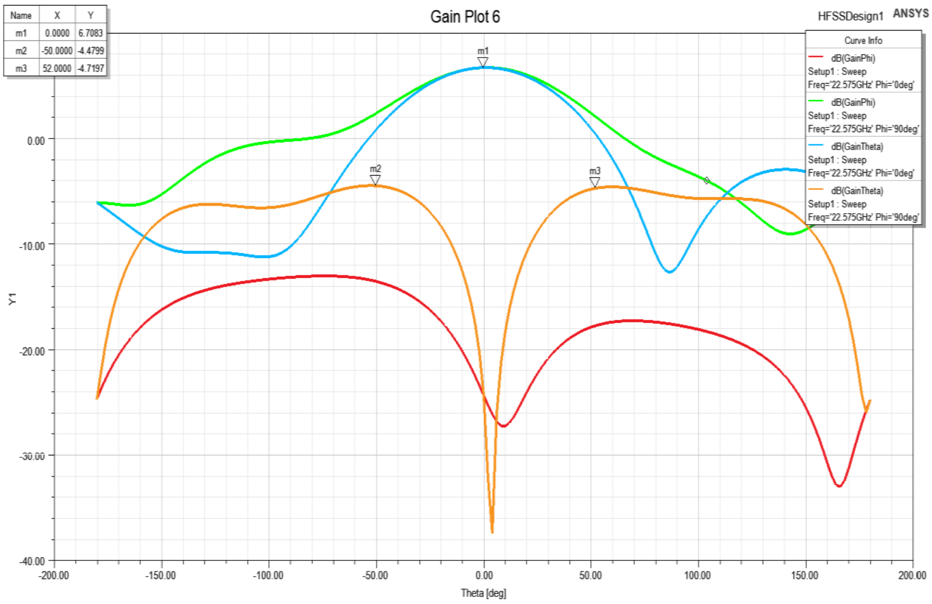


Fig 7(a): Return loss of the antenna with DGS on RT Duroid substrate. Fig 7(b): VSWR of the antenna with DGS on RT Duroid



substrate

Figure 7(c): Gain plots of the antenna with DGS on RT Duroid substrate.

4 CONCLUSION

In this study, a rectangular microstrip patch antenna operating at 38 GHz was designed using two different substrates: FR4 Epoxy and RT Duroid 5880. Both the conventional and defected ground structure (DGS) modified versions were simulated using HFSS software. The antenna built on the Duroid substrate demonstrated superior overall performance, exhibiting higher gain, broader bandwidth, and lower VSWR compared to the

FR4-based design. Applying DGS to the FR4 substrate resulted in a strong return loss of -38 dB and an enhanced bandwidth of 3.15 GHz; however, the gain remained moderate and the VSWR was relatively high. Conversely, the Duroid antenna with DGS achieved a more balanced performance, optimizing gain, return loss, and impedance matching. These findings highlight the effectiveness of DGS in enhancing antenna characteristics and emphasize the critical role of substrate selection in high-frequency antenna design.

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Cite this Article:

Harshiya H, Murthi Mahadeva Naik G, Santhosh Kumar K B, Deepika K C and Sushma N, *"**Design and Analysis of a Microstrip Patch Antenna Operating at 38 GHz**", International Journal of Scientific Research in Modern Science and Technology (IJSRMST), ISSN: 2583-7605 (Online), Volume 4, Issue 6, pp. 06-13, June 2025.*

Journal URL: *https://ijsrmst.com/*

DOI: *https://doi.org/10.59828/ijsrmst.v4i6.330*.