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Gain Enhancement of Microstrip Patch Antenna by Using Novel Air Substrate With U-slotted Patch

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Abstract

Aim: *In this work a Rectangular Microstrip Patch Antenna is designed by replacing conventional substrate with Air substrate and by adding a U shaped slot in Patch for Gain Enhancement.* ***Materials and Methods:*** *The Microstrip Patch Antenna with Air Substrate is used with 20 samples in comparison with FR-4 substrate of 2mm thickness.* ***Results:*** *Simulation is done by using Ansoft HFSS (High Frequency Structure Simulator) software. The performance of the Antenna is analyzed in terms of Gain, Directivity, Return loss, VSWR and enhancement in Gain is by 1.724 dB in comparison with FR-4 substrate. Attained Significance accuracy ratio (< 0.05).* ***Conclusion:*** *Microstrip Patch Antenna with Air substrate and U Slotted Patch performs better in terms of Gain.*

Key-words: Novel Air Substrate, Directivity, Gain, Microstrip Patch Antenna, Return Loss, VSWR, Antenna Design.

1. Introduction

The Research is to enhance Gain of microstrip patch antenna using air substrate with U-slotted Patch. High gain microstrip patch antennas are needed for effective signal reception in many high frequency applications. (Ayn et al. 2018). Nowadays, the need of microstrip patch antennas is increasing rapidly due to less weight and ease of fabrication (Meena and Meena 2015) makes the patch antenna to be used in mobile communication and satellite applications(Baki, Rahman, and Mondal 2019).

Microstrip patch antennas are having many advantages and limitations also. The major limitations are low gain and low efficiency (Kurukshetra et al. 2018). Because of low gain, the antenna leads to poor signal reception in Satellite Communications (S and Raul Yanyachi 2017).To extend the applications to the current technology the gain should be improved. (Divakar and Panda 2013). Inset fed rectangular patch antenna performs better than edge fed patch (Baki, Rahman, and Mondal 2019).

Previously our team has a rich experience in working on various research projects across multiple disciplines (Sathish and Karthick 2020; Varghese, Ramesh, and Veeraiyan 2019; S.R. Samuel, Acharya, and Rao 2020; Venu, Raju, and Subramani 2019; M. S. Samuel et al. 2019; Venu, Subramani, and Raju 2019; Mehta et al. 2019; Sharma et al. 2019; Malli Sureshbabu et al. 2019; Krishnaswamy et al. 2020; Muthukrishnan et al. 2020; Gheena and Ezhilarasan 2019; Vignesh et al. 2019; Ke et al. 2019; Vijayakumar Jain et al. 2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

Many techniques are available to improve the gain, such as by changing the substrate thickness, multi layered antennas, stacked patch configuration (Ekke and Zade 2016). There is a research gap on development of high gain antennas, so our research work focuses on the design of high gain antennas using slotting technique and by changing the substrate material.

2. Materials and Methods

This study was conducted at Antenna and Wave propagation lab in Saveetha School of Engineering. This study was based on gain improvement of microstrip patch antenna using air substrate with U-slotted patch in comparison with FR-4 substrate. Sample size was calculated by using previous study results (Jaafar et al. 2012) using clinicalc.com by keeping alpha error-threshold by 0.05, 95% confidence interval, power 80%. In this study we compare the parameter such as gain with one sample group from previous literature (Jaafar et al. 2012).

The first group refers to the microstrip patch antenna with FR-4 substrate [dielectric constant is 4 with 2mm substrate thickness] containing 20 samples and the second group containing 20 samples with the replacement of FR-4 with Air substrate [dielectric constant is 1 with 2mm substrate thickness] by adding the U-slot in the patch.

Design of Microstrip Patch Antenna using FR-4 Substrate

Microstrip patch antenna is designed by using FR-4 substrate. The dimensions of patch and substrate are calculated by using the design equations of microstrip patch antennas.

patch width:

$$Wp = \left(\frac{c}{2fr}\right) * \frac{\sqrt{2}}{\epsilon r+1} \quad (1)$$

Patch Length:

$$Lp = \left(\frac{lambda}{2}\right) - 2\Delta l \quad (2)$$

$$\Delta l = h * o.412 * \frac{\epsilon eff+0.3}{\epsilon eff-0.258} * \frac{\left(\frac{w}{h}\right)+0.264}{\left(\frac{w}{h}\right)+0.8}$$

$$\in eff = (\in r + 1)/2$$

Ground Length:

$$Lg = Lp + 6h \quad (3)$$

Ground Width:

$$Wg = Wp + 6h \quad (4)$$

Fig. 1 - Design of Microstrip Patch Antenna using FR-4 Substrate at Design Frequency of 3 GHz Using HFSS Simulation Software

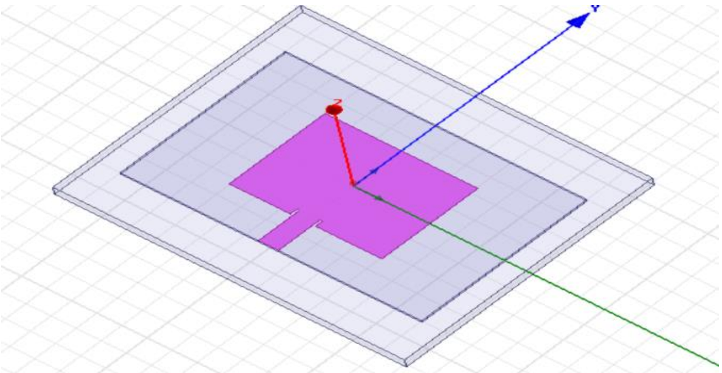


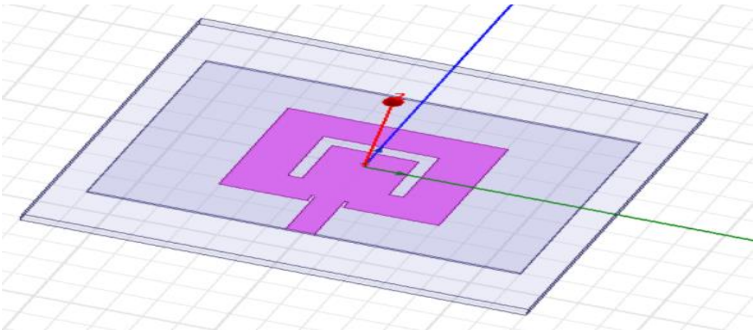
Fig-1 represents the design setup of microstrip patch antenna using Ansoft HFSS software. The FR-4 substrate has a thickness of 2 mm and dielectric constant of 4.4. These properties will make the material to be insulator. This will give good mechanical strength. From the above design equations the length and width patch are obtained [Patch length of 30.41 mm and width of 23.24 mm].

Design of Microstrip Patch Antenna using Air Substrate

To improve the gain of the antenna, the dielectric constant value should be low. Hence the air substrate is used in this design because of its low dielectric constant [dielectric value is 1]. Substrate thickness of 2mm is used.

From fig-2 it was observed that the design of microstrip patch antenna with U-slotted patch. The Air substrate is most suitable for improving the gain because of its low dielectric constant. The dimensions of Air substrate such as length, width and height of substrate are obtained [substrate length is 60 mm, width of 40 mm and height is 2 mm].

Fig. 2 - Design of Microstrip Patch Antenna Using air Substrate with U-slotted at Design Frequency of 3 GHz using HFSS Simulation Software



The testing setup used to design the microstrip patch antenna is Ansoft HFSS software. The system configuration used to set up the testing procedure is Intel Core i3 10th gen Processor. Microstrip patch antenna is designed at a frequency of 3 GHz. To obtain the dimensions of the designing antenna, it requires a resonant frequency which is fixed at a certain value. Antenna variables such as L,W,H,F are defined to construct the antenna in Ansoft HFSS Software. Excitations, boundaries and radiation fields are assigned to the antenna. Analysis setup has been done to add the frequency sweep to the antenna. After Validation, Simulation results are analysed in the HFSS simulation tool.

Statistical analysis: SPSS version 21 was used for statistical comparison of parameters such as gain, directivity. The independent variables are width, height of substrate [width of 40 mm, height of 2mm] length and width of the patch [length of 30.41 mm and width of 23.24 mm], operating frequency. The dependent variables are gain, directivity, return loss and VSWR.

3. Results

The Results of Microstrip patch antenna by using air substrate with U-shaped slotted patch has been designed and simulated results are obtained by using Ansoft HFSS software.

Fig-3 represents the Gain(dB) Vs Frequency (GHz) plot. from fig-3 it was observed that the value of gain at different frequencies. The plot shows the variation of gain at different frequencies in Wave shaped patterns. The red colour indicates the maximum gain obtained for the designed antenna

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and the other colour indicates the lower values away from the resonance. The maximum gain obtained for Air substrate is 6.134 dB.

Fig. 3 – Gain (dB) Vs Frequency (GHz) is Plotted and the Maximum Gain obtained for the Air Substrate at a Frequency of 3 GHz. Red Colour Indicates the Maximum Gain and other Colours Indicates the Reduction of Gain from Maximum Resonance of the Antenna

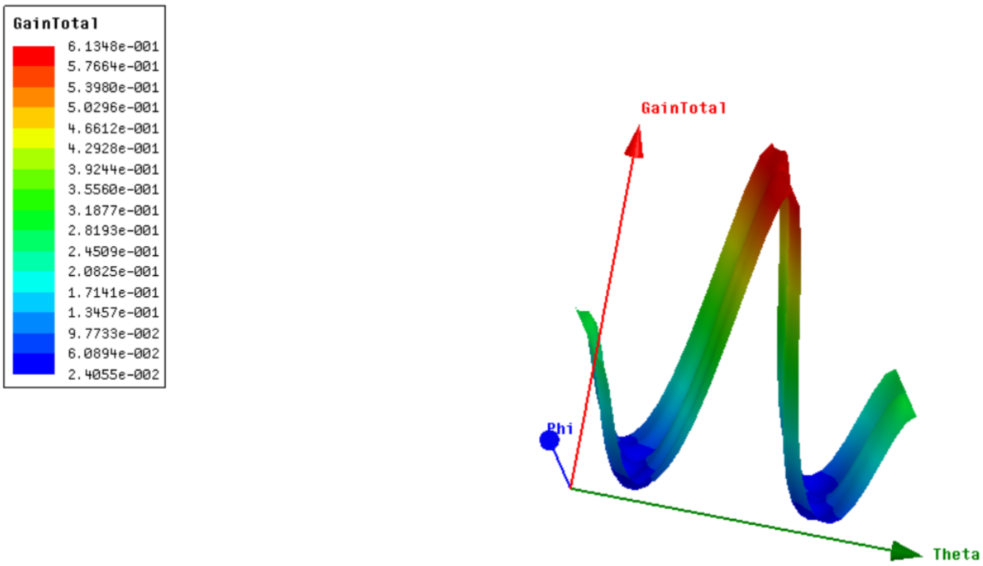

Fig-4 represents the Directivity(dB) Vs Frequency (GHz) plot. The plot shows the variation of directivity at different frequencies in Wave shaped patterns. The red colour indicates the maximum directivity obtained for the designed antenna and the other colour indicates the lower values away from the resonance. The maximum directivity obtained for Air substrate is 6.620 dB.

Fig. 4 - Directivity(dB) Vs Frequency (GHz) is Plotted and the Maximum Directivity obtained for Air Substrate at a Frequency of 3 GHz. Red Colour Indicates the Maximum Directivity and other Colours Indicates the Reduction in Directivity from Maximum Resonance of the Antenna

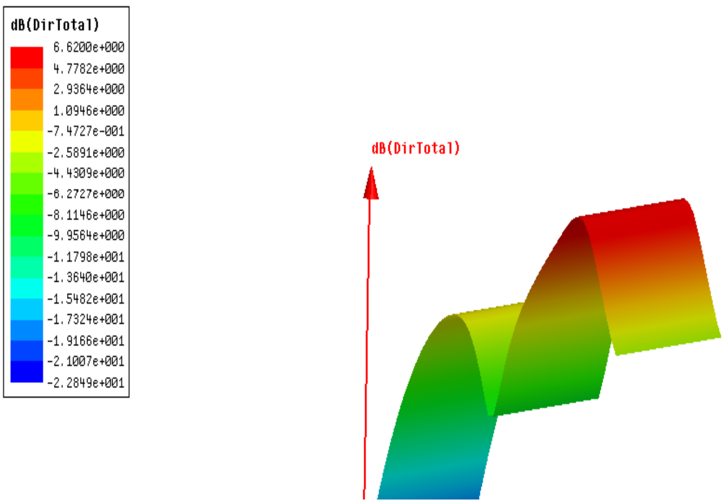

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Fig-5 represents the Return loss(dB) Vs Frequency (GHz) plot. From fig-5 it was observed that the value of return loss obtained for air substrate is -14.2 dB. This value indicated the power loss is less in the designed antenna. Always return loss value should be more negative (<-10 dB) for better performance of the antenna.

Fig. 5 - Return Loss(dB) Vs Frequency (GHz) is Plotted and it shows that the Power Loss is Minimum at Resonant Frequency

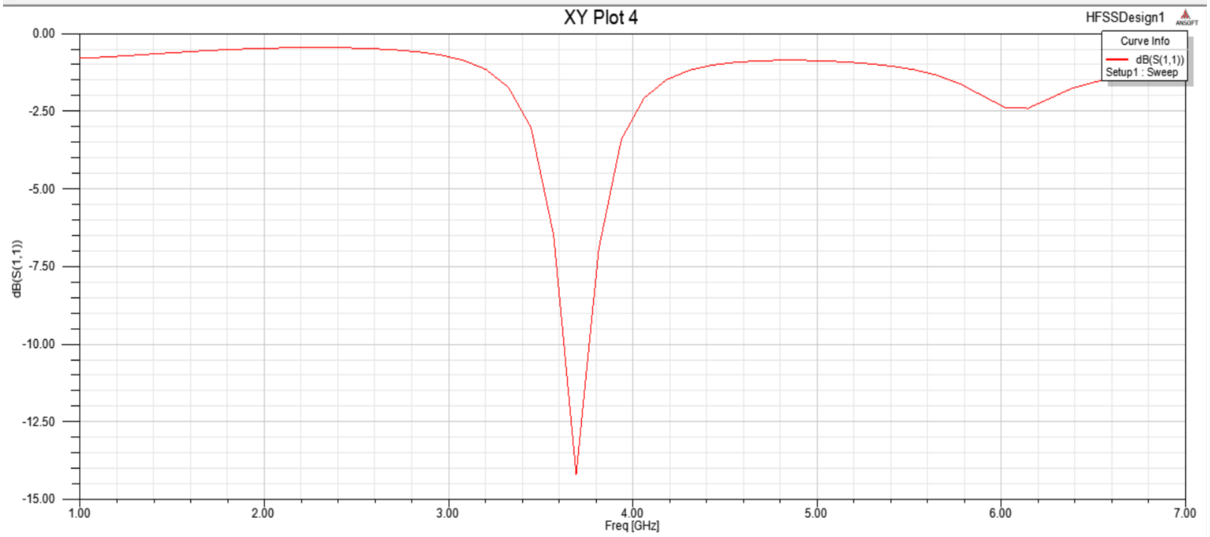
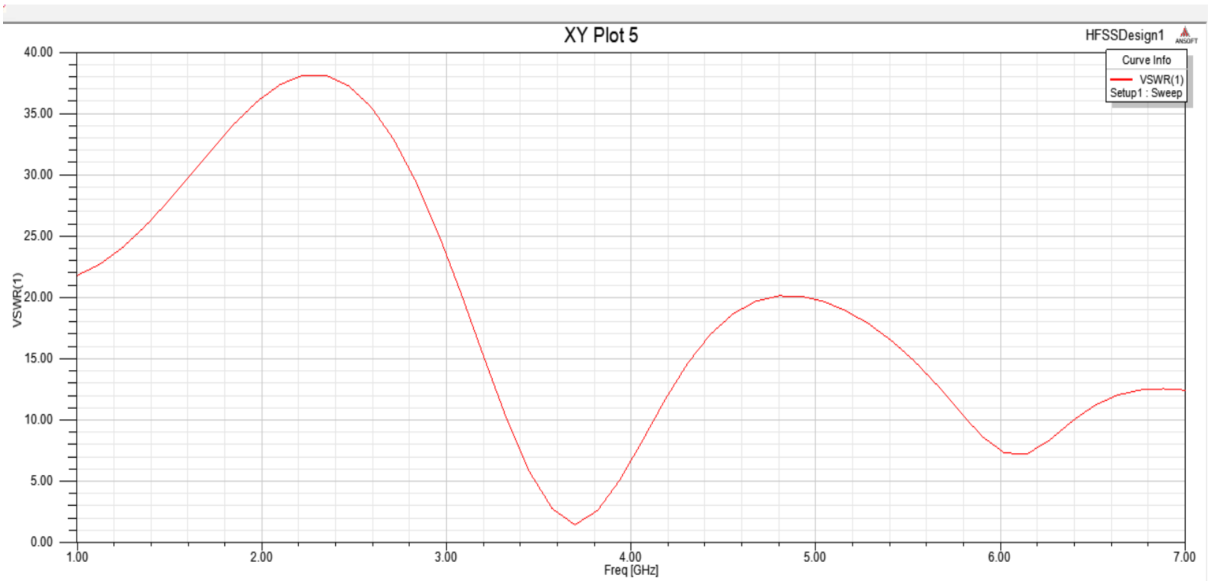


Fig-6 represents the VSWR Vs Frequency (GHz) plot. The VSWR obtained for Air substrate is 1.4 which is minimal and real. For effective performance of the antenna the value should be o to 2.

Fig. 6 - VSWR Vs Frequency (GHz) is Plotted and the Minimum VSWR Value obtained for Air Substrate which is Minimal and Real. Always the Minimum Values of VSWR gives the Better Performance of the Antenna



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From Table-1 it was observed that the data set is collected for values of Gain for two different groups. Group 1 refers to the data obtained from FR-4 substrate and group 2 refers to the Air substrate with U-slotted patch.

Table 1 - Data Set is Collected for the Values of Gain(dB) in Two Groups. Group 1 Refers to the FR-4 Substrate with 20 Samples and Group 2 Refers to the Air Substrate with the U-slotted Patch of 20 Samples

Group [FR-4]	Gain (dB)	Group [Air]	Gain (dB)
1	0.21	2	1.47
1	1.18	2	2.27
1	2.20	2	3.04
1	3.28	2	3.80
1	4.38	2	4.54
1	5.47	2	5.26
1	6.45	2	5.90
1	7.16	2	6.38
1	7.29	2	6.59
1	6.64	2	6.33
1	5.39	2	5.42
1	3.90	2	3.94
1	2.22	2	2.17
1	-0.11	2	0.36
1	-4.28	2	1.61
1	0.84	2	1.32
1	0.70	2	1.43
1	-0.05	2	1.39
1	0.36	2	3.11
1	-0.42	2	4.42

From Table-2 it was observed that comparative analysis of simulation results such as Gain, Directivity, Return loss and VSWR for FR-4 and Air substrate obtained from HFSS software.

Table 2 - Comparison of FR-4 Substrate and Air Substrate with U-slotted Patch Values of Gain, Directivity, Return Loss and VSWR at 3 GHz for Microstrip Patch Antenna

Substrate	Gain	Directivity	Return loss	VSWR
FR-4	4.41 dB	3.172 dB	-13.38 dB	1.5
AIR	6.134 dB	6.620 dB	-14.2 dB	1.4

From Table-3 it was observed that by performing the statistical analysis with 20 samples for air substrate the mean is 3.5375, standard error is 0.445 and the deviation is 1.990. The significance value is smaller than 0.05 shows that the design is good with respect to the output values (Table-4).

Table 3 - Group Statistics Results Reveal that Mean, Standard Deviation and Standard Mean Error for the Air Substrate. It States that the Mean is Higher, Deviation is Lower for Air Substrate Compared with FR-4

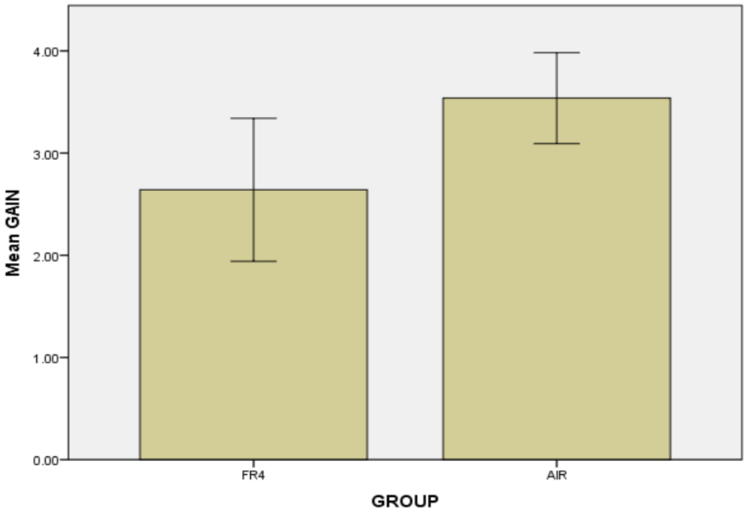
Group Statistics					
	GROUP	N	Mean	Std. Deviation	Std. Error Mean
GAIN	FR4	20	2.6407	3.12720	.69926
	AIR	20	3.5375	1.99032	.44505

Table 4 - Independent Sample T-test for Significance and Standard Error Determination. P Value is less than 0.05 Considered to be Statistically Significant and Confidence Interval were Calculated

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Gain	Equal variances assumed	4.74	.03	-1.082	38	.28	-0.89	.828	-2.57	0.78
	Equal variances not assumed			-1.082	32.2	.28	-0.89	.896	-2.5	0.79

From Fig-7, the bar graph shows the Independent sample t-test used to compare the gain values between FR-4 substrate and Air substrate and statistically significant difference was noticed $P < 0.05$. When compared to the FR-4 substrate the gain improvement using Air substrate with U-slotted patch appears to be improved [Gain improvement of 1.724 dB].

Fig. 7 - Bar Representing the Gain Comparison between FR-4 Substrate and Air Substrate in Terms of Mean Accuracy. The mean Accuracy of Air substrate is better than FR-4 substrate and standard deviation of Air substrate is Lesser than FR-4 Substrate. Mean Accuracy of Detection=+/-1SD.



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4. Discussion

From the results (Fig-3) obtained it is clear that gain value appears to be improved for air substrate compared to FR-4 substrate [Gain improvement of 1.724 dB] and it is statistically significant p(0.036) for air substrate.

The maximum gain obtained for an air substrate (Fig-3) is 6.134 dB when compared to 4.41 dB using FR-4 substrate [Gain improvement of 1.724 dB] and also the other like findings like maximum directivity obtained for the air substrate is 6.620 dB (Fig-4) when compared to 3.172 dB using FR-4 substrate [Directivity improvement of 3.448 dB]. The return loss value obtained for Air substrate (-14.2 dB) (Fig-5) indicates less power loss in signal when compared with FR-4 substrate(-13.38 dB). VSWR value of the designed antenna is (1.4) (Fig-6) which is a minimal value compared to the Fr-4 substrate (1.5). From the above results the performance of the proposed microstrip patch antenna with air substrate appears to be improved.

The factors that affect the results are substrate thickness, feed positions and antenna structure. As substrate thickness increases, gain also increases (Ineneji and Kusaf 2015). Thick material with low permittivity is preferred for better performance of the antenna (Wanjari et al. 2017). Feed positions also plays a vital role in increasing the performance. The feed has to be placed in a correct position in order to match the impedance. If the impedance is properly matched, the loss will be minimized (Šipuš, Bartolić, and Stipetić 1992). Antenna gain is a crucial output parameter for deciding the antenna's efficiency. The gain of an antenna explains how effectively it transforms input power into radio waves that are transmitted in a particular direction (Asnani and Baudha 2019). The gain of the receiver antenna explains how effectively it receives radio waves that are transmitted from the transmitter antenna (Ravi Kumar, Arun Kumar, and Devipradeep 2015). The design structure of the antennas plays an important role in determining the gain (Tomar, Bharadwaj, and Gupta 2019). The maximum gain obtained for an air substrate is 6.134 dB when compared to 4.41 dB using FR-4 substrate [Gain improvement of 1.724 dB]. There is no previous literature with opposing findings in our design.

Our institution is passionate about high quality evidence based research and has excelled in various fields (Vijayashree Priyadharsini 2019; Ezhilarasan, Apoorva, and Ashok Vardhan 2019; Ramesh et al. 2018; Mathew et al. 2020; Sridharan et al. 2019; Pc, Marimuthu, and Devadoss 2018; Ramadurai et al. 2019). We hope this study adds to this rich legacy.

Increment in the dimensions of the patch due to Fringing Effect, to avoid this the quality factor should be within the limit of microstrip patch antenna.

The present work can be extended for multi band frequencies in satellite communications, global positioning system for navigation and wireless communication purpose.

5. Conclusion

Thus, the Microstrip patch antenna with air substrate by introducing U-slotted Patch is designed and analysed. The gain obtained by using FR-4 substrate is 4.21dB. Gain of Air Substrate with U-slotted patch is 6.15 dB. Which appears to be improved by 1.74 dB.

Declarations

Conflict of Interests

No conflict of interest in this manuscript.

Author Contributions

Author SR was involved in data collection, data analysis, manuscript writing. Author SWR was involved in conceptualization, data validation and critical review of manuscript.

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3. Saveetha Institute of Medical and Technical Sciences.
4. Saveetha School of engineering.

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