

Directivity and VSWR Enhancement of Microstrip Patch Antenna at 2.45GHz Using Novel Inset Fed Microstrip Line Feed for Bluetooth Communications in Comparison with Coaxial Probe Feed

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Abstract

Aim: The main objective of this project is to design a rectangular-shaped microstrip patch antenna at a frequency of 2.45GHz to enhance the Directivity and VSWR using Inset fed technique in Bluetooth Communications. **Materials & Methods:** Microstrip patch antenna with microstrip line feed technique and Coaxial probe feed technique is used with a sample size of 40. **Results:** By using HFSS Simulation Software Gain, Directivity, VSWR and Return Loss of Microstrip patch antenna are improved and noted in comparison with Coaxial probe feed antenna. The Simulation Results obtained for the designed antenna are Gain is 2.91dB, Directivity is 6.04dB, Return loss for 2.45GHz, 3.7GHz and 4.5GHz frequencies are -17.1dB, -20.1dB, -17.2dB. VSWR for 2.45GHz, 3.7GHz, 4.5GHz frequencies are 1.3, 1.2, 1.3. Attained significance accuracy ratio $p(<0.05)$ for Gain and Directivity and $p(<0.04)$ for return loss and vswr in Statistical Analysis. **Conclusion:** Performance parameters of Microstrip Patch antenna with microstrip line feed technique appears to be improved when compared with Coaxial probe feed technique. From the results, the proposed antenna can be used for Bluetooth Communications and Tri-band applications.

Key-words: Microstrip Patch, Novel Inset Fed, Gain, Directivity, Return Loss, VSWR, Bluetooth, Tri-Band, Antenna Design.

1. Introduction

The Research is about to design a microstrip patch antenna for bluetooth and wifi applications (Gunaram, Gunaram, and Sharma 2018).The importance of my study is to Transmit and Receive the

information in Bluetooth communication efficiently by improving the Gain, Directivity, VSWR and Return Loss of the proposed antenna using Inset fed mechanism with FR4 Epoxy Substrate at a frequency of 2.45GHz(Rahman 2019; Ng, Uysal, and Leong, n.d.). Compact low-profile multiband and wideband planar antennas are favoured for modern long-range and short-range wireless communication; the only disadvantage of a multiband Microstrip Patch antenna is the narrow bands. (Srivastava et al. 2018).

The requirements of antennas for wireless communication applications are small in size, low cost, and low profile (Rao, Singh, and Mishra 2018). Microstrip patch antennas follow all of these criteria because they are simple to make, inexpensive, low-profile, and small (Bainsla, Singh, and Sahoo, n.d.). However, poor gain and restricted bandwidth are two major disadvantages of microstrip patch antennas (Saxena et al. 2020) (Baudha and Asnani 2018). Microwave frequencies are where microstrip antennas are most widely found (Yadav, Singh, and Melkeri 2017). The Rectangular Microstrip patch antennas, transmission lines, and ground planes are usually constructed of high conductivity metal, such as copper (Baudha and Asnani 2018). The patch has a length of L and a width of W , and it sits on top of a substrate with a thickness of h and permittivity (ϵ_r)(Mahmoud and Hamad 2016). The upper face is radiating surface and lower face is acting as a ground (Yadav, Singh, and Melkeri 2017). So the parameters like Gain, Directivity, Return Loss and VSWR of the antenna should be improved for various applications (Bhaldar et al. 2021; Mondal, Sarkar, and Sarkar 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.

The microstrip patch antennas are the most widely used because they are easy to implement in any system. For Bluetooth and wifi Communications the operating frequency range is 2.45GHz. Hence the designed antenna will be used for bluetooth and wifi communications. Problems in existing Research work are low performance of antenna in terms of low gain, low Directivity, High Return Loss and VSWR. The main aim is to increase the Directivity and VSWR of Microstrip Patch antenna.

2. Materials & Methods

This study was conducted at antenna and wave propagation lab at Saveetha School of Engineering. This Study was based on Microstrip line feed Patch antenna by Comparing with Coaxial Probe feed Patch antenna. Microstrip line feed and Coaxial Probe feed are taken for two groups and have a sample size of 40 (Kane, Phar, and BCPS n.d.). Sample size was calculated by using previous study results (Mabaso et al. 2018) using Clinicalc.com, by keeping alpha error - Threshold by 0.05, 95% confidence interval, pre-test power 80%. In this study we compared the parameters like Gain, Directivity, Return Loss and VSWR by taking 20 samples of Microstrip line feed antenna and 20 samples using previous Literature Study (Mabaso et al. 2018).

Microstrip Patch Antenna Design using Microstrip Line Feeding

Microstrip line feed is one of the cheaper ways to fabricate since it is just a conducting strip connected to the patch and can thus be called a patch extension. Controlling the inset position makes it convenient to antenna and match impedance.

The dimensions of the Patch are designed using following formulae:

Width of the patch is calculated as follows:

$$Pw = \frac{c}{2f\sqrt{(\epsilon_r+1)}/\sqrt{2}} \quad (1)$$

Effective Dielectric Constant (ϵ_{eff}) of antenna is calculated as:

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[1 + \frac{12h}{Pw} \right]^{-\left(\frac{1}{2}\right)} \quad (2)$$

Effective length of patch is calculated as:

$$\text{Eff. Length } L_{eff} = \frac{c}{2f\sqrt{\epsilon_{eff}}} \quad (3)$$

Length of extension ΔL is the additional length due to the fringing fields and it is calculated as:

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

Actual length of patch is calculated using:

$$Pl = L_{eff} - 2\Delta L \quad (5)$$

Ground Length and Width is calculated from:

$$\text{Ground Length } Gl = 6h + Pl \quad (6)$$

$$\text{Ground Width } Gw = 6h + Pw \quad (7)$$

Proposed antenna Width and Length of patch calculated from the above equations are:

$$\text{Patch Width } Pw = 38mm$$

$$\text{Patch Length } Pl = 29.4mm$$

Microstrip Patch Antenna Design using Coaxial Probe Feeding

Coaxial Probe feeding is a feeding method in which the inner conductor of the coaxial probe is attached to the radiation patch of the antenna while the outer conductor is connected to the ground plane.

Testing Setup and Configurations used to design Microstrip Patch antenna are HFSS Software in Core i5 8th Gen Intel Processor (8MB Cache up to 4.2GHz) Windows 10. Microstrip Patch Antenna was designed at a frequency of 2.45GHz and is taken as the input for the mathematical and practical design of the antenna. Variables of the antenna like L,W,H,F are defined to construct the antenna in HFSS Software. Excitations, Boundaries and Ports are assigned to the antenna after construction. Analysis setup and frequency sweep is added to the antenna. After Validating and analysis of the antenna, Simulations results were analysed in HFSS Software.

Statistical Analysis

SPSS Version 21 was used for statistical Comparison of Parameters like Gain, Directivity, VSWR and Return Loss. The independent variables are width and Height of the substrate, length and width of Patch and Operating Frequency of Antenna. And the dependent variables are Gain, Directivity, Return loss and VSWR of the antenna.

3. Results

The Proposed antenna is simulated in HFSS Software and performance parameters like Gain, Directivity, VSWR and Return Loss of antenna are Calculated from the simulation results.

From Fig. 3 Return Loss Vs Frequency at 2.45GHz, 3.7GHz and 4.5GHz is plotted and the maximum return loss for microstrip line feed are -17.1dB, -20.16dB, -17.2dB which shows that the proposed antenna can operate at tri band frequencies. From Fig.4 VSWR Vs Frequency at 2.45GHz, 3.7GHz and 4.5GHz is plotted and the Obtained VSWR for microstrip line feed are 1.32, 1.21, 1.31 which Shows that the proposed antenna can operate at tri band frequencies.

Fig. 1 - Proposed Microstrip Patch Antenna Design (FR4 - ϵ_r of 4.4, Pw= 38mm, Pl= 29.4mm, Substrate thickness = 1.6mm) at 2.45GHz using Inset Fed Technique

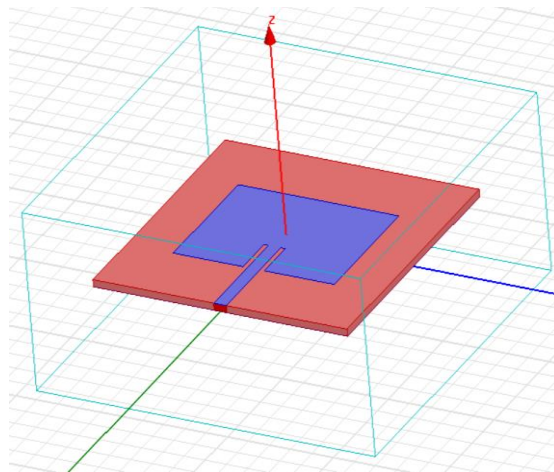


Fig. 2 - Microstrip Patch Antenna Design (FR4 - ϵ_r of 4.4, Pw= 30mm, Pl= 38mm, Substrate Thickness = 1.6mm) at 2.45GHz using Coaxial Probe Fed Technique

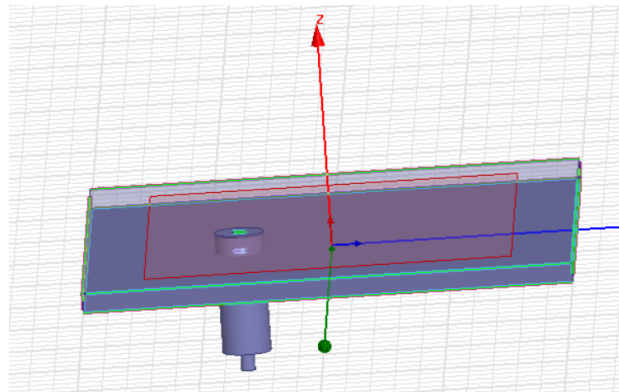


Fig. 3 - Return Loss Vs Frequency is Plotted and obtained Return Loss for Microstrip Line Feed are -17.1dB, -20.16dB, -17.2dB which shows that the Proposed Antenna can Operate at tri-band Frequencies

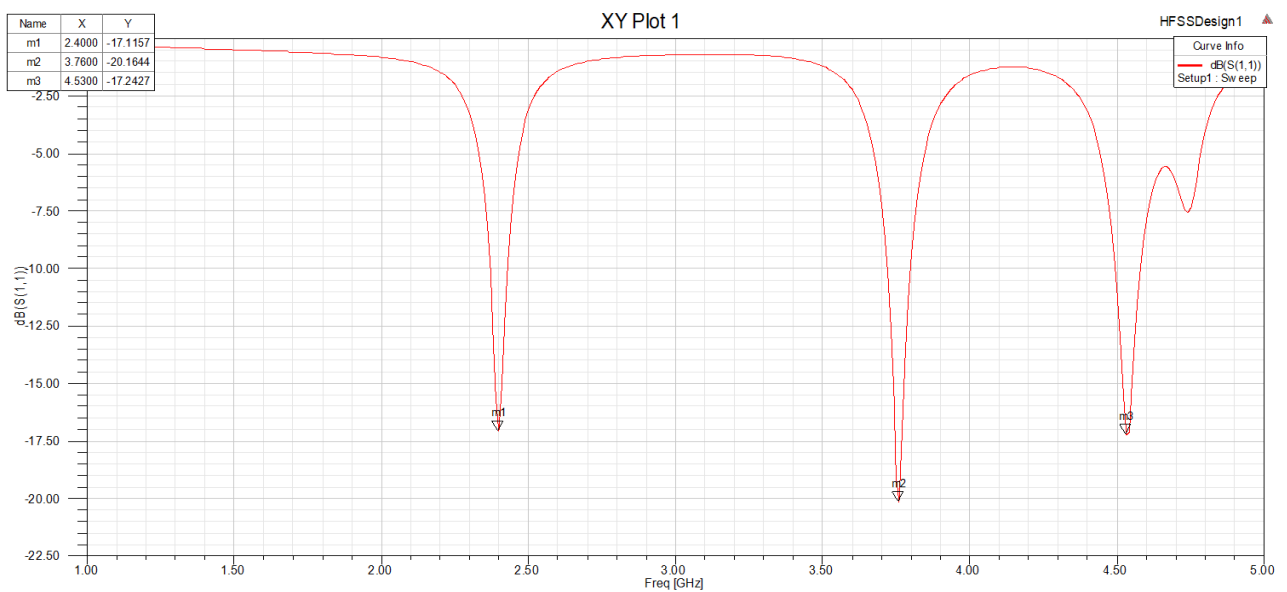


Fig. 4 - VSWR Vs Frequency is Plotted and the Obtained VSWR for Microstrip line feed are 1.32, 1.21, 1.31 which Shows that the Proposed Antenna can Operate at Tri Band Frequencies

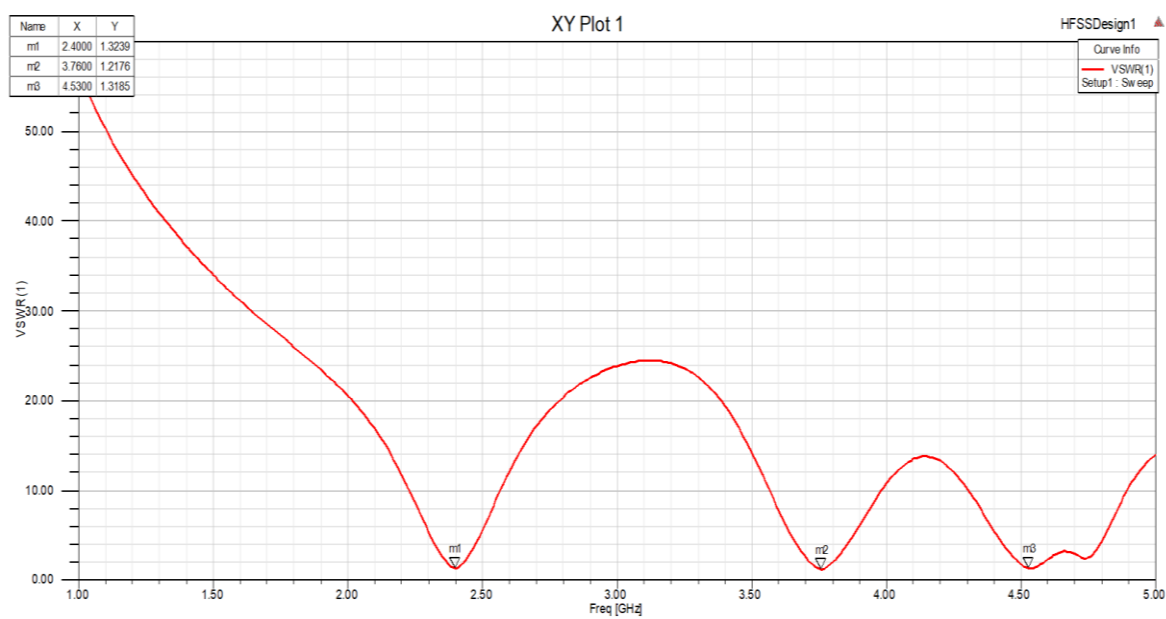
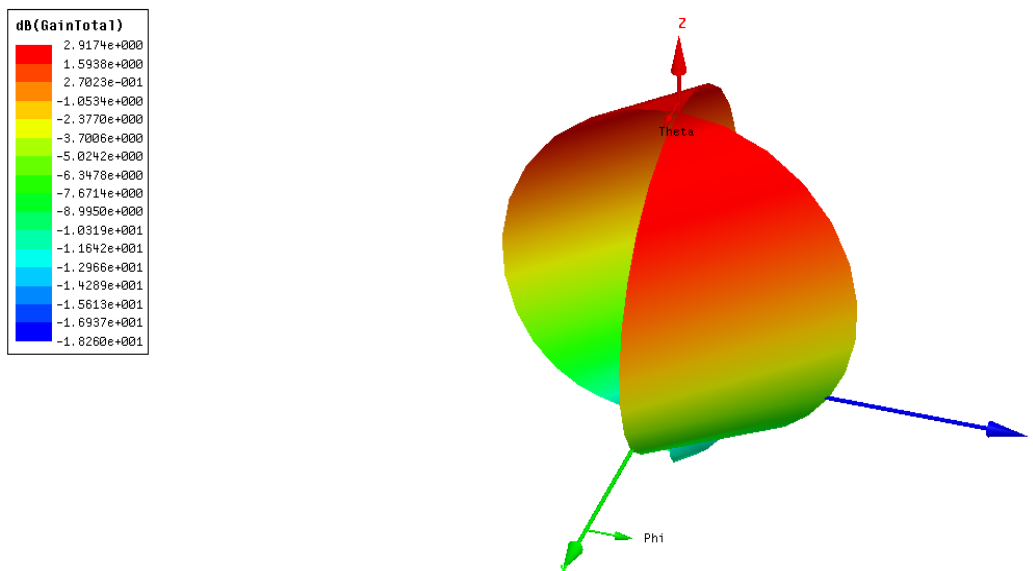


Fig. 5 - Total Gain (dB) Vs Frequency (GHz) is Plotted and the Maximum Gain obtained for Microstrip Patch Antenna Using Microstrip Line Feed at 2.45GHz Frequency is 2.917db. Red Colour Indicates the Maximum Gain of the Antenna and Blue Colour Indicates the Minimum Gain of the Antenna



From Fig.5 & Fig.7 Total Gain(dB) Vs Frequency(GHz) and Total Directivity(dB) Vs Frequency(GHz) is Plotted and the maximum gain obtained for microstrip patch antenna using microstrip line feed at 2.45GHz frequency is 2.917db. And the maximum Directivity obtained for microstrip line feed is 6.042db at 2.45GHz. Red colour indicates the maximum gain of the antenna and blue colour indicates the minimum gain of the antenna.

Fig. 6 - Frequency Vs Phi(deg) Radiation Pattern, Total Gain is 2.91dB. Red Line indicates gain at 0deg and Blue line indicates gain at 90deg.

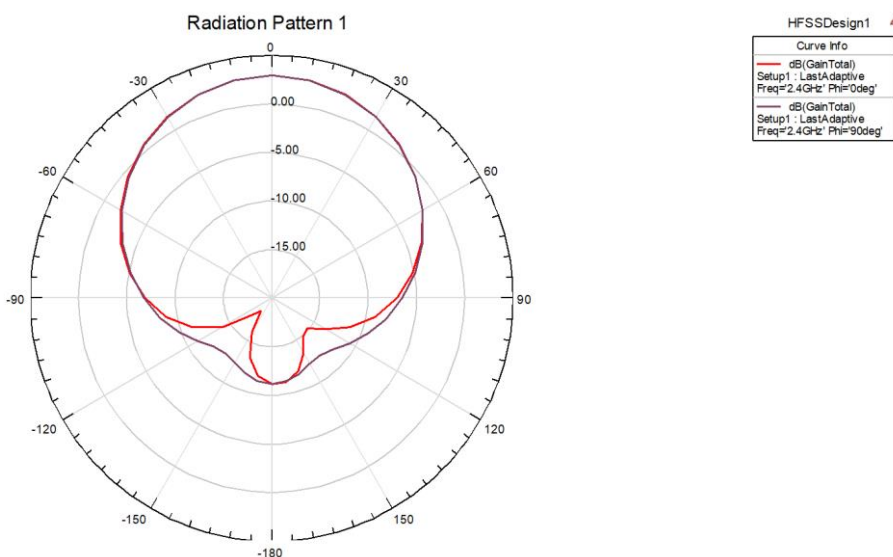
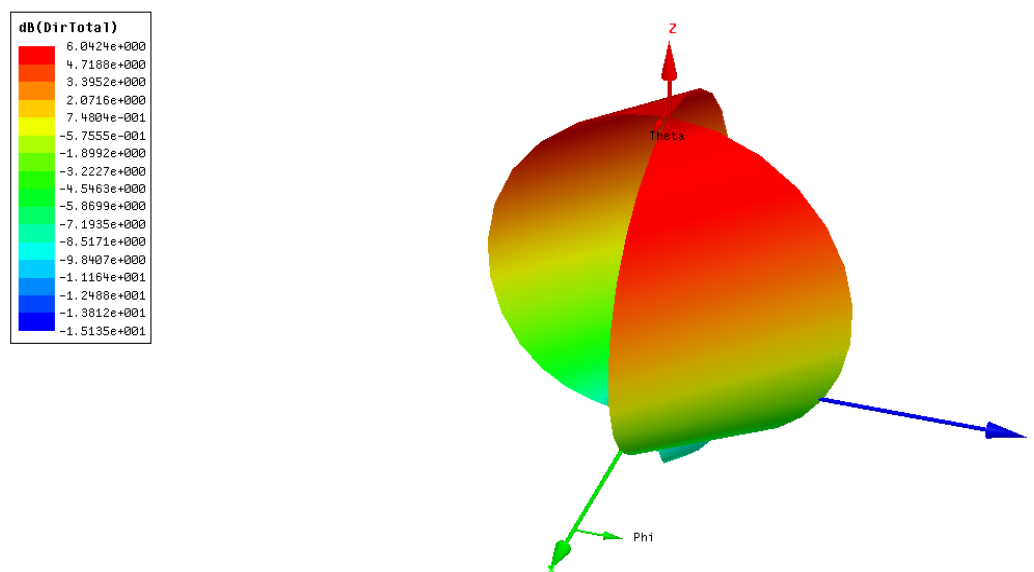


Fig. 7 - Total Directivity(dB) Vs Frequency (GHz) is Plotted and the Maximum Directivity obtained for microstrip line feed is 6.042db at 2.45GHz. Red Colour Indicates the Maximum Gain of the Antenna and Blue Colour Indicates the Minimum Gain of the Antenna



From Table 1: Data is Collected in HFSS Simulation Software for Microstrip Line Feed Antenna and Coaxial Probe Feed Antenna like Gain, Directivity, Return Loss and VSWR are tabulated. 20 data samples are collected for each group (Microstrip Line Feed and Coaxial Probe Feed). Comparison of Microstrip Line feed with Coaxial Probe feed Parameters (Gain, Directivity, Return Loss, VSWR) at 2.45GHz for Inset Fed Microstrip Patch antenna with FR4 - epoxy Substrate with thickness of 1.6mm is tabulated in Table 2.

Table 1 - Comparison of Microstrip Line feed with Coaxial Probe feed Parameters (Gain, Directivity, Return Loss, VSWR) at 2.45GHz for Inset Fed Microstrip Patch antenna with FR4 - epoxy Substrate with thickness of 1.6mm

Group	Gain	Directivity	Return Loss	VSWR
Coaxial Probe Feed	4.35dB	4.35dB	-23.36dB	1.8
Microstrip Line Feed	2.91dB	6.04dB	-20.1dB	1.21

Table 2 - Data is Collected for Antennas like Gain, Directivity, Return Loss and VSWR for two Groups Microstrip Line Feed and Coaxial Probe Feed

Group 1 (Microstrip Line Feed)				Group 2 (Coaxial Probe Feed)			
Gain	Directivity	Return Loss	VSWR	Gain	Directivity	Return Loss	VSWR
2.16	1.01	-3.28	5.35	-3.43	-4.43	36	-1.5
3.65	2.4	-17.12	1.32	-3.19	-4.26	40	-1.7
4.26	3.63	-3.15	5.57	-2.95	-3.92	30	-2.1
4.14	4.65	-1.44	12.12	-2.7	-3.86	28	-2.4
1.97	5.41	-1.01	17.14	-2.46	-3.24	26	-2.6
0.83	5.88	-0.85	20.41	-2.22	-3.12	22	-2.8
1.4	6.04	-0.77	22.53	-1.98	-2.86	20	-3.1
2.51	5.89	-0.73	23.86	-1.74	-2.32	18	-3.4
3.53	5.44	-0.71	24.46	-1.5	-2.01	15	-4
4.5	4.7	-0.72	24.16	-1.26	-1.92	14	-4.2
5.7	3.71	-0.77	22.63	-1.01	-1.64	12.5	-4.4
0.01	2.52	-0.9	19.39	-7.72	-7.93	16	-4.6
13.08	1.17	-1.23	14.18	-5.31	-5.68	18.2	-3
54.25	-0.29	-2.26	7.72	-2.89	-2.92	18	-3.1
17.53	-1.79	-7.32	2.51	-4.75	-4.82	14	-4
1.12	-3.3	-9.53	2	2	2.82	2	-7.1
0.48	-4.79	-2.87	6.11	1.94	2.64	1.8	-10
0.4	-6.23	-1.62	10.78	4.35	5.23	1.18	-23.3
0.36	-7.55	-1.29	13.49	1.94	2.64	1.8	-10
0.57	-8.59	-1.31	13.24	2	2.82	14	-4

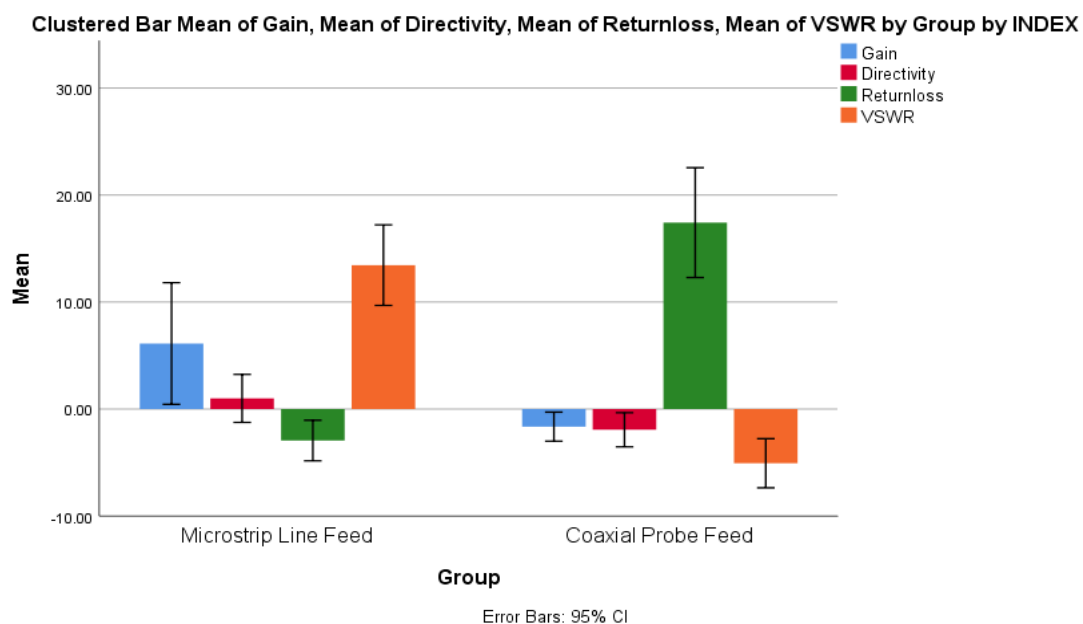
Table 3- Group Statistics Results Reveal that Standard Deviation is Low and Mean High for Microstrip Line Feed for Gain, Directivity, VSWR and Return Loss When Compared with Coaxial Feed

Group Statistics					
	Group	N	Mean	Std. Deviation	Std. Error Mean
Gain	Microstrip Line Feed	20	6.1223	1.90213	2.71675
	Coaxial Probe Feed	20	-1.6434	2.90047	.64856
Directivity	Microstrip Line Feed	20	.9950	3.24560	1.07205
	Coaxial Probe Feed	20	-1.9390	3.41172	.76288
Return Loss	Microstrip Line Feed	20	-2.9442	4.05873	.90756
	Coaxial Probe Feed	20	17.4240	10.96513	2.45188
VSWR	Microstrip Line Feed	20	13.4489	8.04579	1.79909
	Coaxial Probe Feed	20	-5.0650	4.89933	1.09552

Table 4 - Independent Sample T- Test Results for Microstrip Line Feed Antenna Reveals that $p(<0.05)$ which shows that Statistical Significance when Compared with Coaxial Probe Feed

Independent Samples Test										
Groups		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	3.851	.057	2.780	38	.008	7.76570	2.79309	2.11137	13.4200
	Equal variances not assumed			2.780	21.15	.011	7.76570	2.79309	1.95979	13.5716
Directivity	Equal variances assumed	3.241	.080	2.230	38	.032	2.93404	1.31578	.27038	5.59770
	Equal variances not assumed			2.230	34.31	.032	2.93404	1.31578	.26095	5.60713
Return Loss	Equal variances assumed	10.72	.002	-7.79	38	.000	-20.368	2.61445	-25.660	-15.075
	Equal variances not assumed			-7.79	24.11	.000	-20.368	2.61445	-25.762	-14.973
VSWR	Equal variances assumed	9.175	.004	8.789	38	.000	18.5139	2.10640	14.2497	22.7781
	Equal variances not assumed			8.789	31.38	.000	18.5139	2.10640	14.2200	22.8078

Fig. 8 - Bar Graph Represents the Performance of the Antenna Comparison between Microstrip Line Feed and Coaxial Probe Feed. It Shows that the Performance is Better for Microstrip Line Feed than the Coaxial Probe Feed (Independent Sample T- test means = +/-1SD)



4. Discussions

Based on the above statistical analysis, the performance of the microstrip patch antenna appears to be better for microstrip line feed than for coaxial probe feed. Using SPSS Software, we find that Microstrip Line feed is statistically significant $p(<0.05)$ for Microstrip Strip Patch Antenna.

The $S(1,1)$ parameter of an antenna, also known as Return Loss of Antenna, depicts the input-output relationship between ports (Gul and Eker 2020). All of the power is reflected when $S(1,1)$ is 0dB. If Return Loss is -10dB, 3dB of total power is passed to the antenna, with a -7dB reflected power loss (Bainsla, Singh, and Sahoo, n.d.). An antenna's Return Loss must be less than -10dB in order to work properly. Return Loss for Proposed antenna at frequency of 2.45GHz is -17.1dB, 3.7GHz is -20.1dB and 4.5GHz is -17.2dB. The VSWR is used to measure the antenna's power reflection. It specifies how the impedance of an antenna's transmission line is matched. The VSWR value should be positive and true; the lower the vswr, the higher the antenna's output. The VSWR of an antenna should be between 0 and 2.5 in order to function properly (Baudha and Asnani 2018; Mondal, Sarkar, and Sarkar 2019). The obtained VSWR for microstrip line feed at 2.45GHz, 3.7GHz and 4.5GHz frequencies are 1.32, 1.21, 1.31. 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 (Baudha and Asnani 2018; Mondal, Sarkar, and Sarkar 2019). Total Gain and Directivity of the Proposed Microstrip Line Feed antenna is 2.91dB and 6.04dB. There is no opposing citation and the design done based on the above procedure appears to be good.

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.

Low gain is the disadvantage using Microstrip line feed (Inset fed) technique in Microstrip Patch Antenna.

Multiple feed lines can be used for MIMO (Multiple Input and Multiple Output) 5G Communications.

5. Conclusion

Microstrip Patch antenna was designed at a frequency of 2.45GHz by using microstrip line feed and Compared with Coaxial probe feed antenna, The Simulation Results obtained for the designed

antenna are Gain is 2.91dB, Directivity is 6.04dB, Return loss for 2.45GHz, 3.7GHz and 4.5GHz frequencies are -17.1dB, -20.1dB, -17.2dB. VSWR for 2.45GHz, 3.7GHz, 4.5GHz frequencies are 1.32, 1.21, 1.32 thus the performance parameters like Gain, Directivity, VSWR, Return Loss. Microstrip Line Feed values appear to be better Compared with Coaxial Probe Feed from the simulation results in HFSS Software, the proposed antenna can be used for Bluetooth Communications and Tri-Band applications.

Declaration

Conflict of Interests: No Conflict of Interest in this Manuscript.

Author Contributions

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

Acknowledgement

Authors would like to acknowledge Saveetha School of Engineering for providing all of the research information needed for this study, as well as their ongoing assistance and support.

Fundings: We thank the following organizations for providing financial support that enabled us to complete the study.

1. Vajenthura Microwave Products Pvt. Ltd.
2. Saveetha University.
3. Saveetha Institute of Medical and Technical Sciences.
4. Saveetha School of engineering.

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