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Bandwidth Enhancement of Novel E-shaped Microstrip Patch Antenna with FR4 Substrate at 2.45GHz

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Abstract

Aim: *The main objective of this project is to enhance the Bandwidth of microstrip patch antenna by using an E-shaped slot on the patch and varying substrate thicknesses in comparison with the Rectangular patch antenna.* ***Materials and Methods:*** *The microstrip patch antenna with an E-shaped slot and with varying substrate thicknesses of four groups [1.2mm, 1.6mm, 1.8mm, 2.4mm] is used with a sample size of 40 in comparison with rectangular patch antenna of another group with sample size 10.* ***Results:*** *By using Altair Feko simulation software, the proposed antenna parameters such as Bandwidth and Gain are obtained. The results are Gain=9dB, Bandwidth=225MHz for 1.2mm, Bandwidth=250.1MHz at 1.6mm, Bandwidth=252MHz at 2.4mm substrate thicknesses and bandwidth of conventional Rectangular patch antenna of 1.6mm substrate thickness=243MHz. Attained Significance accuracy ratio p(<0.05).* ***Conclusion:*** *The bandwidth appears to be enhanced (12%) by varying the substrate thicknesses [1.2mm to 2.4mm] from 225MHz to 252MHz.*

Key-words: Radar, FR4, Bandwidth, Gain, Novel Patch, Telemetry, Directivity, Substrate, S-band, FEKO, Antenna Design.

1. Introduction

The Research is about the Bandwidth Enhancement of the E-shaped microstrip patch antenna by varying the thickness of FR4 substrate (Padmavati and Lalitha 2019). The importance of this study is the need for high antenna bandwidth to support high data rate and multi user communications

(Tejeswee and Verma 2018). This is used in Applications such as bluetooth, Wi-Fi, radars and telemetry (Rao and V. 2014).

The Microstrip patch antennas need to meet the requirements of small size, less weight, low cost, and low profile to achieve wireless connectivity (Balanis 2005). They also have limitations such as poor bandwidth, lower gain and efficiency (Kumar and Ray 2003). So the bandwidth and gain of the microstrip patch antennas has to be improved (Nandgaonkar, Deosarkar, and Shah 2007; Rafique, Khalil, and Saif-Ur-Rehman 2017; Al-Ahmadi and Khraisat 2019)). Because of these features, Microstrip patch antennas are widely suggestable for satellite communications (Salarian and Mirshekar-Syahkal 2019), WLANs (Kurukshetra et al. 2018), Missiles and telemetry (Malisuwan et al. 2015), GPS systems (Nandgaonkar, Deosarkar, and Shah 2007), mobile communications (Nandgaonkar, Deosarkar, and Shah 2007; Rafique, Khalil, and Saif-Ur-Rehman 2017), etc.

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 main Problem in existing Research work is the poor antenna bandwidth and need to operate in a wide range of frequencies to achieve high Data rates. Hence, the bandwidth of the microstrip antennas has to be enhanced for various applications.

2. Materials and Methods

This study was conducted at Antenna and wave propagation lab in Saveetha School of Engineering. The study was based on the microstrip patch antenna design with E-shaped patch of different substrate thicknesses in comparison with the rectangular patch antenna. Sample size was calculated by using previous study results (Parmar, Makwana, and Jajal 2012) using clincalc.com by keeping alpha error-threshold by 0.05, 95% confidence interval, Pre-test power 80%. In this study, we compare the parameters like Gain, Bandwidth, Directivity by taking 10 samples, one sample group by using previous literature (Parmar, Makwana, and Jajal 2012).

Rectangular patch and E-shaped patch of four different substrate thicknesses are taken for five groups and have a sample size of 50. Each group contains 10 samples of Directivity by varying the frequencies ranging from 2.2 to 2.6GHz.

It has been known that the performance of the microstrip antenna can be increased by inserting the slots on the rectangular patch and by varying the substrate thickness. In this work, we inserted an E-shaped slot on the patch in order to get the enhanced bandwidth of the antenna. The E-shaped Microstrip patch has been designed with dimensions of W_{rp} x L_{rp} at the operating frequency f_{ro} = 2.45GHz, with dielectric FR4 substrate. The width and length of the patch are calculated by using the following expressions mentioned below (Ang and Chung 2007):

$$W_{rp} = \frac{\propto}{2f_{ro}\sqrt{\frac{\varepsilon_{ro}+1}{2}}} \qquad (1)$$

$$L_{ep} = \frac{\propto}{2f_{ro}\sqrt{\varepsilon_{ep}}} \qquad (2)$$

Here, W_{rp} is the width of the patch, '**α**' is the velocity of the light in free space, f_{ro} is the Resonant frequency and ε_{ro} is the dielectric constant value of the FR4, ε_{ep} is the effective di-electric constant and L_{ep} is the effective length where,

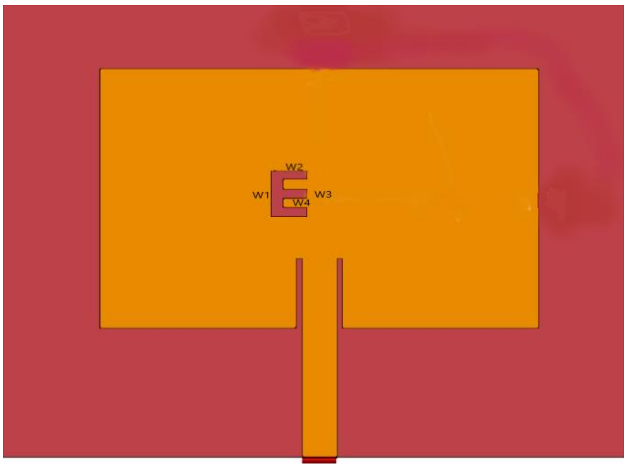
$$\boldsymbol{\varepsilon}_{ep} = \frac{\varepsilon_{ro}+1}{2} + \frac{\varepsilon_{ro}-1}{2}\sqrt{\left[1+12\left(\frac{h_{rp}}{w_{rp}}\right)\right]} \qquad (3)$$

$$\Delta l = 0.412\, h_{rp} * \frac{(\varepsilon_{ep}+0.3)\left(\left(\frac{W_{rp}}{h_{rp}}\right)+0.264\right)}{(\varepsilon_{ep}-0.258)\left(\left(\frac{W_{rp}}{h_{rp}}\right)+0.8\right)} \qquad (4)$$

The actual length of the patch L_{rp} is obtained from:

$$L_{rp} = L_{ep} - 2\Delta l \qquad (5)$$

Fig. 1 - Design of Microstrip Patch Antenna with E-shaped slot on the rectangular patch with FR4 substrate at 2.45GHz using Altair Feko software.



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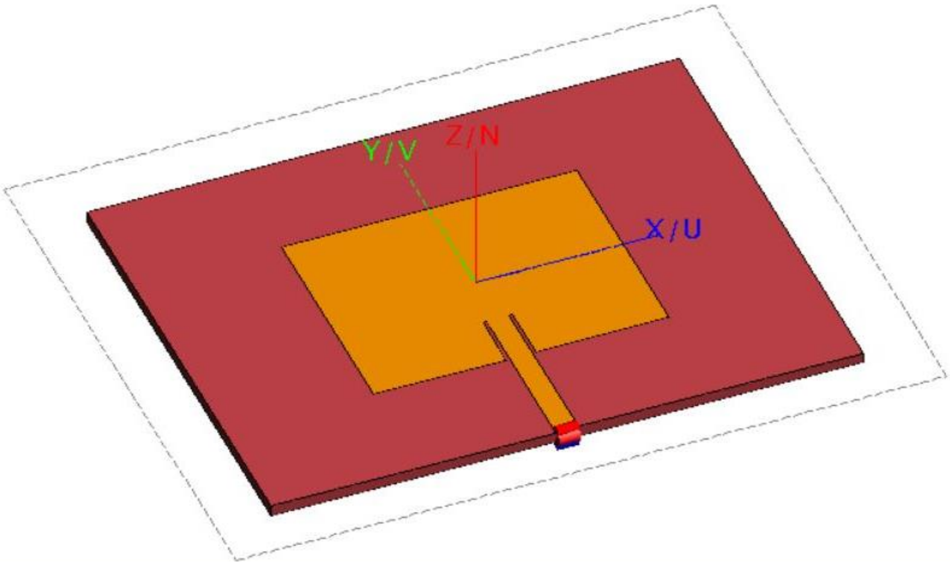
By substituting the values of f_{ro}=2.45GHz, **α**=3*10^8 m/s and ε_{ro}=4.4, the length of the patch and width of the patch is obtained as 29.3401 and 38.062mm. The dimensions of the proposed e-shaped slot are w1=5mm, w2=4mm, w3=1mm and w4=1mm as shown in fig. 1.

Rectangular patch (without any slots) is basically used in the design of the conventional microstrip patch antennas. In this design, the microstrip line feeding technique is used to feed the antenna as shown in Fig. 2.

Fig. 2 - Design of Microstrip Patch Antenna with rectangular patch using FR4 substrate at 2.45GHz in the Altair Feko software



Testing Setup and configurations used to design the proposed antenna are Altair FEKO software in core i5 8th gen Intel processor (8MB cache up to 4.2GHz). The E-shaped microstrip antenna is designed at a frequency of 2.45GHz which is taken as the input for mathematical analysis. Variables of the antenna like L, W, H, F are defined to construct the proposed antenna in FEKO. Far-fields, ports, voltages are requested and assigned once the design of the antenna is completed. After running the Feko solver, Antenna parameters such as Gain, Directivity etc, were obtained if no errors were raised in the solver. The bandwidth of E-shaped patch and rectangular patch is noted in table 1.

Table 1 - Comparison of E-shaped patch antenna and Rectangular Patch Antenna Parameters (Gain and Bandwidth) at 2.45GHz having 1.6mm substrate thickness which shows that the bandwidth of the E-shaped patch is high compared with the Rectangular patch.

Group	Bandwidth (MHz)	Gain(dB)
Rectangular patch	243.7	6.0
E-shaped patch	250.1	9.0

Table 2 - Bandwidth of the proposed E-shaped patch antenna by varying the FR4 substrate thicknesses [1.2mm, 1.6mm, 1, 8mm, 2.4mm] having dielectric constant ε_{ro}=4.4 at 2.45GHz

Substrate thickness(mm)	Bandwidth of proposed antenna (MHz)
1.2	225.7
1.6	250.4
1.8	249
2.4	252.73

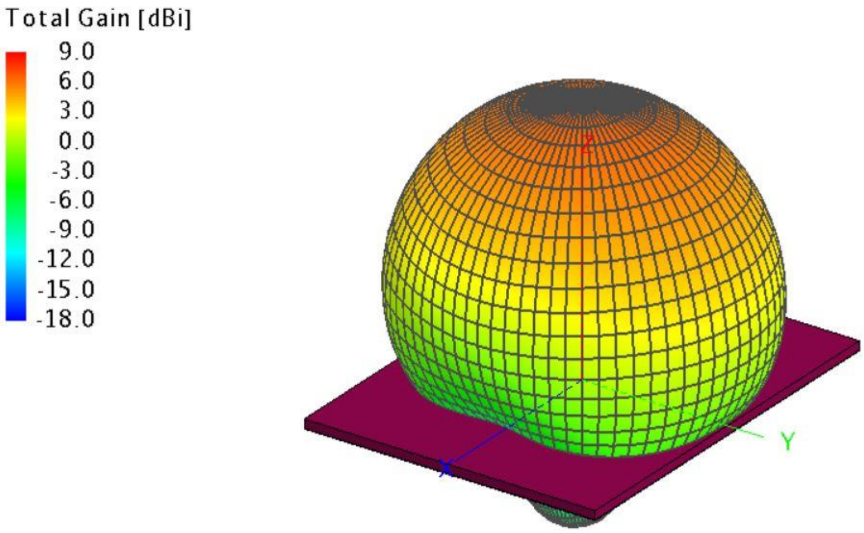
3. Statistical Analysis

SPSS version 21 was used for the statistical comparison of Directivity. The independent variables are width and height of the substrate, length and width of the patch, and operating frequency of the antenna. The Dependent variables are Gain, Directivity and Bandwidth of the antenna.

4. Results

The proposed E-shaped Microstrip patch antenna with FR4 substrate is simulated in Altair FEKO software and the performance parameters such as Bandwidth, Gain and Directivity are calculated from the simulation results. The maximum Gain is represented in Red colour at resonance and the value reduces when it is away from the resonance. The antenna is resonating at one frequency band between 2GHz-3GHz where reflection coefficient is minimum and bandwidth is obtained at -3dB.

Fig. 3 - The 3-D plot of antenna gain is plotted with frequency at 2.45GHz. The maximum gain obtained as 9.0dB for an E-shaped microstrip patch antenna. Red colour indicates the maximum Gain of the antenna and blue indicates the minimum Gain



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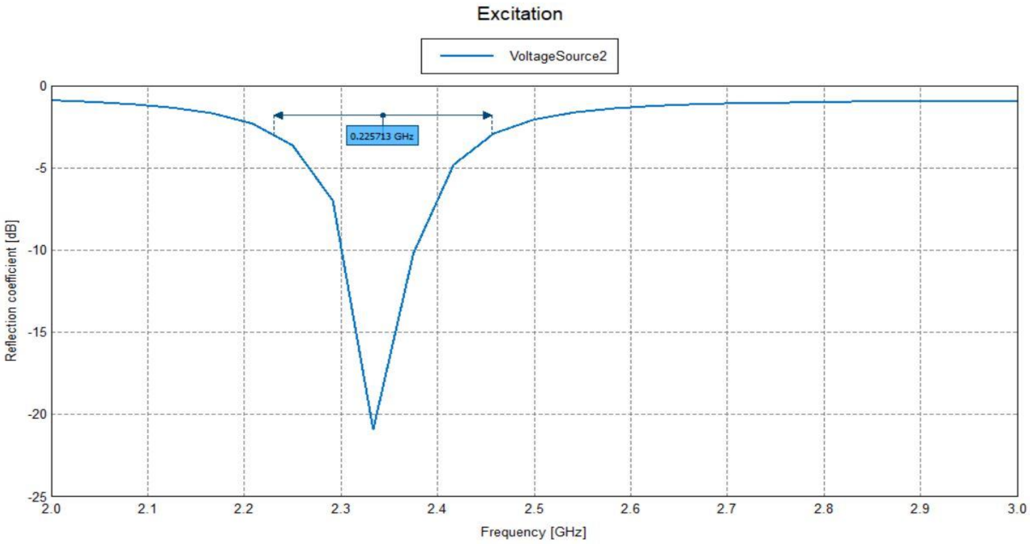
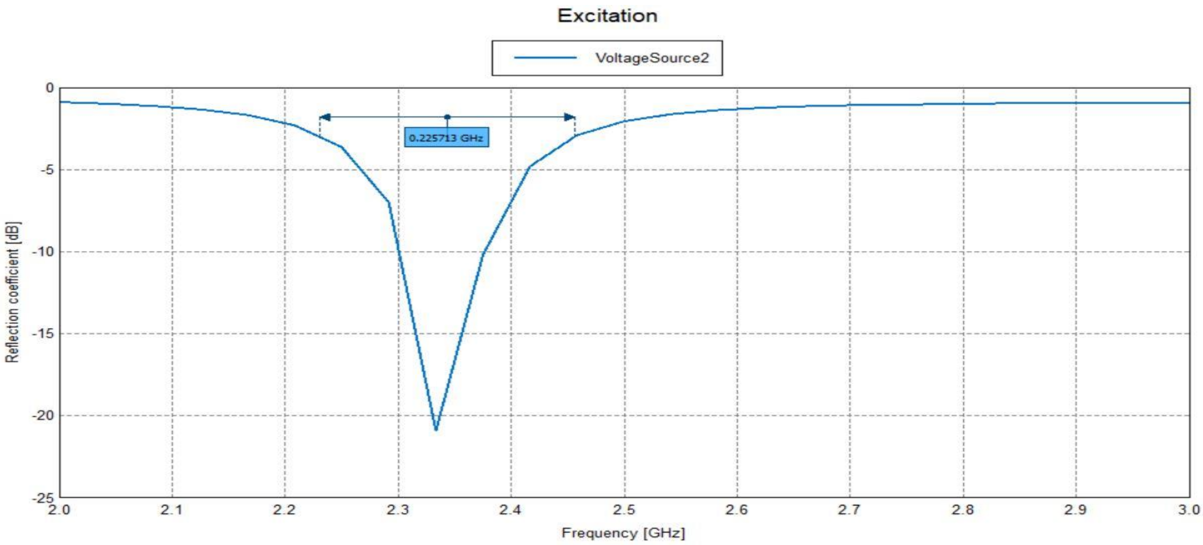
From Fig 3, it was observed that the maximum gain of the designed antenna is obtained at the resonance as 9.0dB which is indicated by red colour. The gain value decreases when it is away from the resonance and minimum gain is represented by the blue colour.

Fig. 4 - Reflection Coefficient (dB) vs. Frequency (GHz) is Plotted in the Frequency Range 2GHz to 3GHz, Bandwidth of the E-shaped patch antenna with substrate thickness h=1.2mm is obtained as 225.7MHz



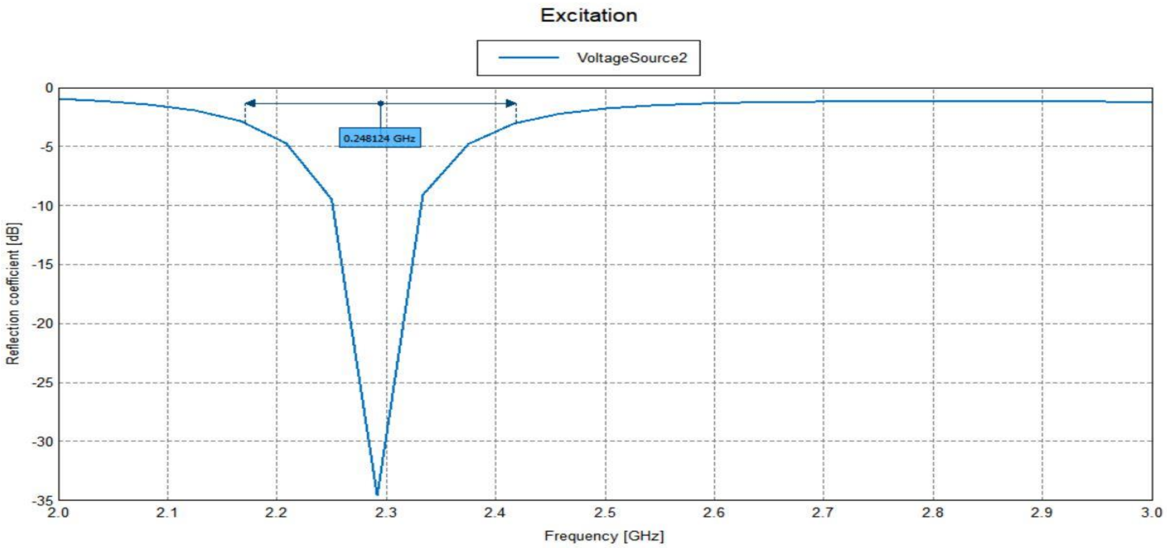
From Fig 4, it was observed that the bandwidth of an E-shaped patch antenna having 1.2mm substrate thickness is 225MHz and the designed antenna gives better performance in the frequency range of 2.24GHz-2.45GHz.

Fig. 5 - Reflection Coefficient(dB) vs. Frequency (GHz) is Plotted in the frequency range 2GHz to 3GHz, Bandwidth of the E-shaped patch antenna with substrate thickness h=1.6mm is obtained as 250.4MHz



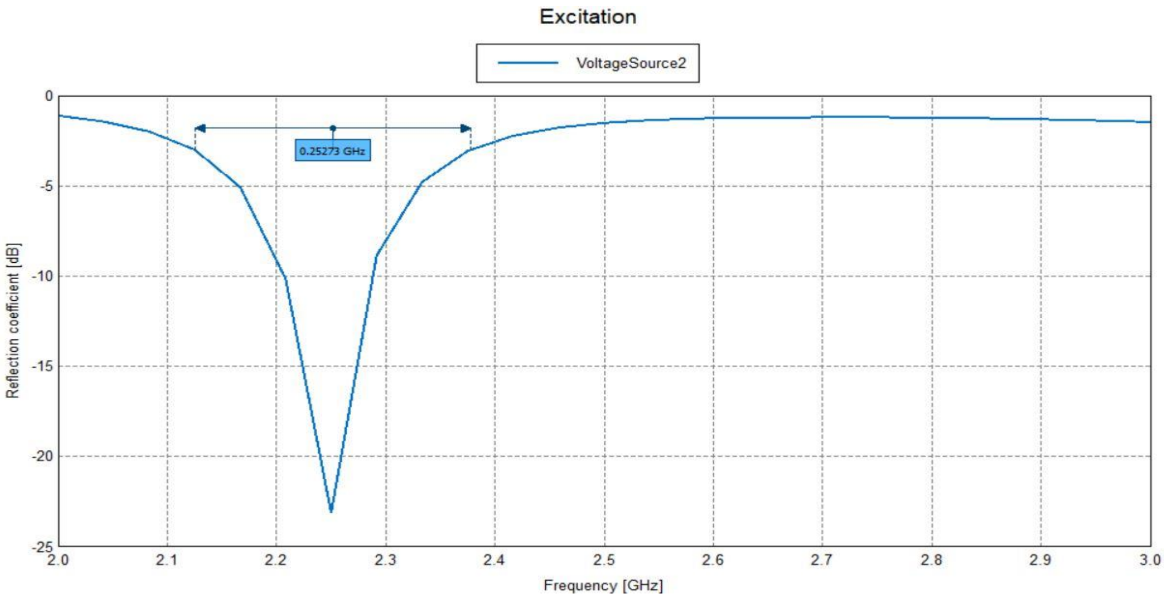
From Fig 5, it was observed that the bandwidth of the designed E-shaped microstrip patch antenna having 1.6mm substrate thickness is 250.7MHz. This antenna shows better performance in the frequency range of 2.24GHz-2.45GHz.

Fig. 6 - Reflection Coefficient(dB) vs. Frequency (GHz) is Plotted in the Frequency Range 2GHz to 3GHz, Bandwidth of the E-shaped patch antenna with substrate thickness h=1.8mm is obtained as 249MHz



From Fig 6, it was observed that the bandwidth of an E-shaped patch antenna having 1.8mm substrate thickness is 249MHz. This antenna gives better performance in the frequency range of 2.17GHz-2.43GHz.

Fig. 7 - Reflection Coefficient(dB) vs. Frequency (GHz) is Plotted in the Frequency Range 2GHz to 3GHz, Bandwidth of the E-shaped Patch Antenna with Substrate Thickness h=2.4mm is obtained as 252.7MHz.



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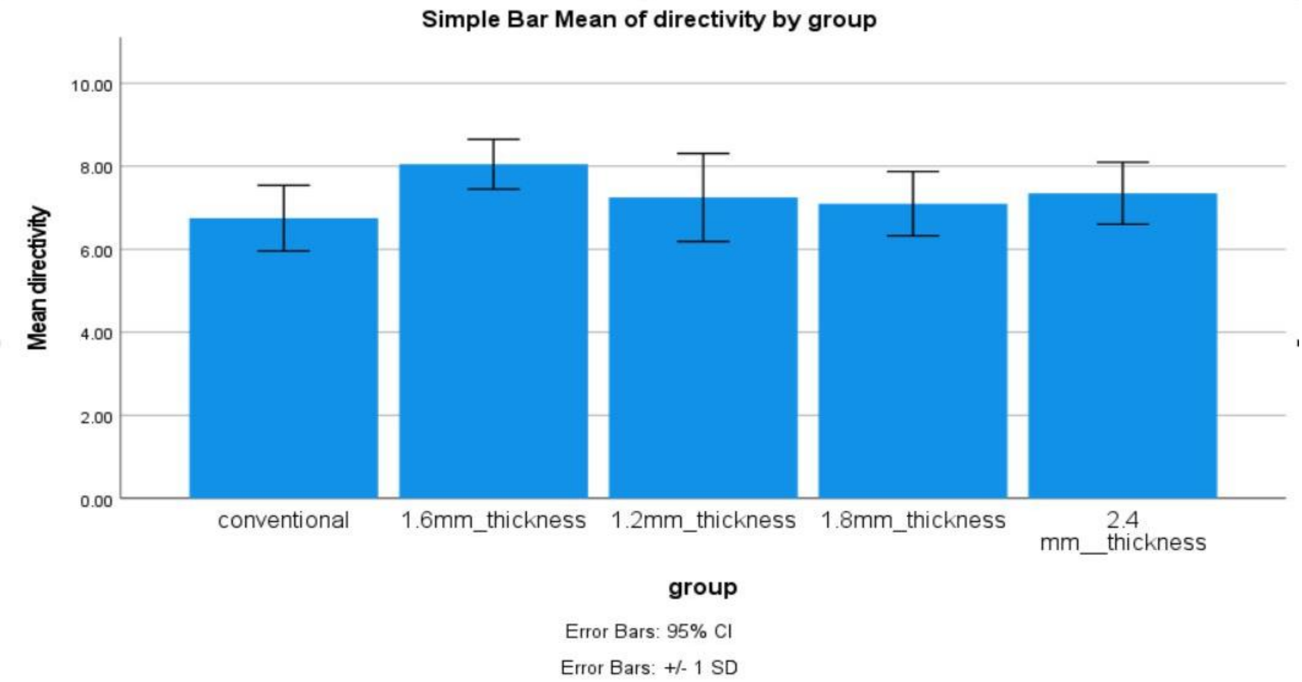
From Fig 7, it was observed that the bandwidth of the proposed patch antenna having 2.4mm substrate thickness is 252MHz. This designed antenna gives better performance in the frequency range of 2.17GHz-2.43GHz.

Fig. 8 - Bars Representing the Mean Directivity(dB) of Rectangular Patch Antenna(6.75dB) and E-shaped patch antenna with four different substrate thicknesses.It shows that the performance is better for E-shaped patch than the rectangular patch(Independent Sample T-test means=+/-1SD).



In performing statistical analysis of 10 samples in terms of directivity, E-shaped patch obtained as 0.79 standard deviation with 0.25 standard error while Conventional rectangular patch obtained as 0.50 standard deviation with 0.189 standard error (Table 3). The significance value smaller than 0.05 showed that our hypothesis holds good. With respect to changes in the input values (independent variables) the corresponding output values (dependent variables) also changes (Table 4).

Table 3 - Group Statistics Reveal that the mean Directivity of the proposed E-shaped patch antenna is high(8.75) when compared with Rectangular patch antenna(6.75). The standard deviation of E-shaped patch is low(0.52) when compared with rectangular patch(0.79).

Group	N	mean	Standard deviation	Std.error mean
Rectangular patch	10	6.75	0.79	0.2500
E-shaped patch	10	8.05	0.5	0.189

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Table 4 - Independent sample T-test results for E-shaped patch antenna reveals that p=0.017(<0.05) which shows statistical significance when compared with rectangular patch antenna.

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
Directivity	Equal variances assumed	6.94	.017	-4.14	18	.001	-1.30	.313	-1.95	-.641
	Equal variances not assumed			-4.14	16.7	.001	-1.30	.313	-1.96	-.637

Independent t-test was used to compare the Directivity of two patches and a statistically significant difference was noticed (P < 0.05). The bandwidth of the proposed antenna at 1.6mm substrate thickness is obtained as 249MHz (Figure 4). Bandwidth of microstrip antenna with single patch is upto 50MHz (Parmar, Makwana, and Jajal 2012) and for conventional antenna is up to 47MHz (Parmar, Makwana, and Jajal 2012; Al-Ahmadi and Khraisat 2019) and bandwidth of the H-shaped patch is 110MHz ("[No Title]" n.d.). When compared with the other patches, the E-shaped patch achieved better bandwidth.

5. Discussions

Based on the above results, the performance of the E-shaped microstrip patch antenna appears to be better than the Rectangular patch antenna at 1.6mm thickness. From SPSS Simulation, E-shaped patch is statistically significant (p<0.05) for microstrip antennas.

The Bandwidth of the antenna depends on the substrate thickness and slots on the patch (Colburn and Rahmat-Samii 1999; Kim, Kim, and Chun 2007). It is obtained from the plot of the reflection coefficient with respect to the frequency at -3dB (Colburn and Rahmat-Samii 1999; Kim, Kim, and Chun 2007; Nagpal, Dillon, and Marwaha 2013). The bandwidth of the E-shaped patch antenna is obtained by varying substrate thicknesses [1.2mm, 1.6mm, 1.8mm, 2.4mm] are 225MHz, 250MHz, 249MHz and 252MHz.

The Antenna gain is a crucial output parameter for deciding the antenna's efficiency (Rao and V. 2014). The Gain of the antenna explains how effectively it transmits the input power into radio waves that are directed in a particular direction (Baudha and Asnani 2018). The maximum Gain and Directivity of the proposed E-shaped patch antenna is obtained at 2.45GHz as 9.0dB. There is no opposing citation and the design done based on the above procedure appears to be good.

In the analysis made by parmar, they have used the single parasitic patch. Their results indicate that the single patch has obtained the bandwidth as 110MHz and maximum Gain as 6.6dB(Parmar, Makwana, and Jajal 2012).This above article is in pair with the proposed analysis as the bandwidth has been enhanced by inserting the slots on the patch.

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.

This design fails to meet the antenna requirement i.e, small size. Because the size of the antenna increases by increasing the substrate thickness.

In future, the bandwidth can be improved by using Multiple slots, stacked geometry, different nano substrate materials to achieve the High Data rates and Multiple users support for 5G communications.

6. Conclusion

The bandwidth appears to be enhanced (12%) by varying the substrate thicknesses [1.2mm to 2.4mm] from 225MHz to 252MHz for E-shaped microstrip patch antenna compared with the conventional rectangular patch antenna. The proposed E-shaped Microstrip patch antenna is designed to resonate in S-band frequencies which finds the applications for Bluetooth, Wi-Fi and Radar standards.

Declarations

Conflict of Interest

No conflict of interest in this manuscript.

Author Contributions

Author NVR was involved in Data collection, data analysis and manuscript writing. Author SWR was 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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