Design of Wearable Microstrip Patch Antenna Using T-Shaped Slot Antenna Compared with U-Shaped Slot Antenna for Health Monitoring Systems

Mannem Meghana[1]; Bhaskarrao Yakkala[2*]

[1]Research Scholar, Department of Electronics and Communication Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India.

[1]meghanareddy55555@gmail.com

[2*]Project Guide, Department of Electronics and Communication Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India.

[2*]bhaskarrao@saveetha.com

Abstract

*Aim: To Enhance radiation characteristics such as bandwidth, gain and Voltage Standing Wave Ratio (VSWR) by designing innovative wearable T-shaped and U-shaped slot microstrip patch antennas using the FEKO tool for health monitoring systems by using FR4 substrate for an operating frequency ranging from 2.2 to 2.6 GHz. **Materials and methods:** The microstrip patch antenna ground plane is made with FR4 material by using FEKO software varying frequency between 2.2-2.6 GHz. The T-Shaped and U- shaped slot microstrip patch antennas was chosen as a group having 20 samples each. The bandwidth, gain and VSWR was obtained for T-shape and U-shape slot antennas. **Results:** T-shaped slot antennas (P=0.001) have significantly higher bandwidth, gain and lower VSWR than the U-shaped slot antenna (P=0.031).The obtained significance value is <0.005 and mean values also increased. **Conclusion:** T-shaped microstrip patch antenna is designed and simulated using FEKO tool. The T-shape slot antenna has higher bandwidth, gain (Mean of T-shape 2.7238 and U-shape 1.4626) and VSWR (Mean of T-shape 8.3951 and U-shape 6.7675) when compared to U-shaped slot antenna. So, this antenna is very suitable for health monitoring systems.*

Key-words: Wearable Antenna Design, Innovative Microstrip Patch Antenna, Bandwidth, Gain, VSWR, FEKO Tool, SPSS Software.

1. Introduction

An antenna is a bowl shaped metallic structure device that receives and transmits the electromagnetic radio waves (Singh et al. 2018). The microstrip patch antennas are popular over decades because of its low cost, low profile, light weight and ease of fabrication. (Shanwar and Othman 2017). The antennas are having many applications in various fields like medical (Raju, Phani Kishore, and Madhav 2019) satellite (Green et al. 2017) and military (Sreelakshmy, Ashok Kumar, and Shanmuganantham 2017). For medical applications, the antenna should have flexibility, less cost, high gain and wide bandwidth (Kumar, Badhai, and Suraj 2018). But the U-shaped slot antenna provides less bandwidth. So, a T-shaped slot antenna is designed, because it provides high compatability for health monitoring systems because it is having wide bandwidth, gain and VSWR. In today's world antenna is used for health monitoring from home without going to hospital. Biomedical applications of the patch antenna are useful by the doctor or by themselves in tracking the health conditions of patients residing remotely, and with medical results and subsequent regulation of diet is possible. The patient does not need to visit the hospital often, as the doctor can track the condition of the patient from his desk (Corchia et al. 2017). The applications of wearable microstrip patch antennas in health monitoring systems are detecting the tumor and brain cancer. Sometimes the patients will suffer with unexpected hormonal imbalance, weight loss and gain. Patients should concern doctors every time for checking these health problems(Corchia et al. 2017; Dhayabarani et al. 2018) (Corchia et al. 2017).

In recent years many papers have been published related to this research work. In IEEE Xplore 25 papers and in science direct 101 papers are published. (Sukhija and Sarin 2017a) has proposed a u-shaped meandered slot antenna for ISM-band applications at the operating frequency of 2.45GHZ. With and without meandered slots are introduced. The antenna is fabricated with FR4 substrate. In free space and muscle models the experimental values and results of antennas are compared. The bandwidth of this antenna is high. So, this antenna can be used in health monitoring systems. The problem of this work is gain is less. (Sukhija and Sarin 2017b) slotted microstrip-fed patch antennas are proposed by using Empire XCcel for biomedical and wireless applications. For S11< -10 dB the designed antenna showing the impedance bandwidth of 2714 MHz. By including other slots in the design, the antenna can be used in WiMAX and WLAN applications at operating frequency range of 2.865-2.096. Based on radiation characteristics such as VSWR, gain, return loss and radiation pattern the design of the antenna is distinguished and it shows good similarity in results of simulated and measured. Less bandwidth is the main drawback in this work. The U- shaped

microstrip patch antenna is designed and simulated by varying the Substrates using HFSS software. The operating frequency range of this antenna is 2.4-2.6 GHz. Bandwidth, gain and return loss are noted and compared. The results show that PDMS is suitable for health monitoring systems. Problem in this work is narrow bandwidth and less gain (Panda, Gupta, and Acharya 2020). The new ultra-wide band planar antenna is designed for microwave imaging and this antenna is operated at frequency range 2.9-10.8 GHz. Patch is designed on FR4 substrate (ε_r=4.3) and it is flexible for multi-viewing imaging. The substrate is designed with thickness h (h=1.575) and slots are inserted for reducing the size hence, gain and bandwidth are enhanced. Drawback of this work is narrow bandwidth (Latif 2020). In the above papers a u-shaped meandered slot antenna for ISM-band applications is best suitable for this research work because this antenna provides wide bandwidth when compared to other antennas.

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.

Monitoring the patient's health using health monitoring systems is very easy than going to hospital. But antennas used in monitoring systems should have wide bandwidth and high gain. In the existing system wearable U-shaped slot microstrip patch antenna is designed for health monitoring systems. But U-shape slot antennas have less bandwidth, gain and high VSWR. Because of narrow bandwidth this antenna cannot be used for long distances. By using a u-shaped slot of microstrip patch antenna in health monitoring systems, the health of patients who live a long distance cannot be monitored from the hospital. The aim of work is to design the T-shaped slot microstrip patch antenna by using FEKO tool for enhancing gain, bandwidth and VSWR.

2. Materials & Methods

This research work is done in Saveetha School of Engineering, SIMATS in Nanoelectronics laboratory. This proposed work contains two groups. The first group refers to the U-shape slot microstrip patch antenna and the second group refers to the T-shape slot microstrip patch antenna. Each group comprises 20 samples. The total sample size of this research work is 40. Sample size was

calculated by using previous study results, in Clincalc.com by keeping threshold 0.05%, G power 80%, confidence interval 95 % and enrollment ratio as 1(Panda, Gupta, and Acharya 2020).

The sample preparation of group 1 is about wearable U-shaped slot microstrip patch antenna. A FEKO tool is required for designing. The gain, bandwidth and VSWR of wearable U-shaped slot microstrip patch antenna are taken. In order to design U-shape slot microstrip patch antenna provide the needed values of variables like thickness (1.6 mm), substrate (FR4), media, voltage(reference impedance = 50 ohm), frequency range(2.2-2.6 GHz) and geometry in CAD feko. Then give mesh as standard(1.43171) and farfield. Click on FEKO solver for simulation. Then click on POSTFEKO to get results for required values. The obtained samples were analysed by using the POSTFEKO.

The sample preparation of group 2 is designing and simulation of a wearable T-shaped slot microstrip patch antenna by varying frequency.The gain, bandwidth and VSWR of wearable T-shaped slot microstrip patch antenna was analysed. For designing the antenna first open the CADFEKO in the feko tool and give the values of variables which are needed. Then give mesh, voltage source and farfield. For simulating the antenna click on feko solver. After that open POSTFEKO and note down the results.

Mathematical Calculation

The Mathematical calculation for calculating the values of dimensions, the below formulas are used and the antenna is designed with obtained values.

(i) Width of patch (W)

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon r+1}{2}}} \qquad (1)$$

C- Speed of light

ε_r - Dielectric constant

f_0 – Operating frequency

By using the above formula (1) the width of the patch is calculated.

(ii) Effective dielectric constant (ε_{reff}) formula is:

$$\varepsilon_{reff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}\left[1 + \frac{10h}{w}\right]^{-\frac{1}{2}} (2)$$

Where h is the thickness of the substrate and w is the width of the patch. The effective dielectric constant is calculated by substituting the values of dielectric constant(ε_r=4.4), width(w) and thickness(h) in equation (2).

(iii) Length of patch

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon\varepsilon_{reff}}} - 2dl \qquad (3)$$

The length of the patch is a very important factor for designing an antenna. Because the operating frequency is decided by the length of the patch. In equation (3) dl is an extension of length. C is the speed of light in vaccum.

(iv) Impedance of branch

$$Z_{\frac{\lambda}{4}} = \sqrt{Z_0 Z_e} \qquad (4)$$

In the above formula (4), gZ_0 is reference impedance of feed line and Z_e is impedance at edge of patch, $\frac{\lambda}{4}$ is quarter wavelength.

T-Shaped rectangular microstrip patch antenna is designed with dimension values of width of the patch(w_p), width of the feed(w_f), length of patch(l_p), length of the feed(l_f) and height of the substrate (h).

The ground plane of rectangular microstrip patch antenna for two sample groups is designed using FR4, a dielectric boundary material. Dielectric constant (ε_r) of FR4 material is 4.4 and tangent value (tan δ) is 0.017. Operating frequency range of this antenna is 2.2GHz to 2.6GHz. Voltage source with reference impedance 50ohm and magnitude 1 is given. Simulation of the designed antenna is carried out using FEKO solver and values of gain, bandwidth and VSWR from the cartesian graph are noted down. Comparative analysis of the gain, bandwidth and VSWR of T-shaped slot antenna and U-shaped slot antenna is done.

The T-shaped and U-shaped slot microstrip patch antennas were designed by using FEKO tool. Gain and VSWR of T-shaped and U-shaped slot microstrip patch antennas are collected by varying the frequency (2.2-2.6 GHz) and bandwidth was calculated

Statistical Analysis

For statistical analysis the SPSS software is used. The values obtained from the FEKO tool are extracted into SPSS software to calculate the mean and significant values. Here the mean values should be high and significance values have to be less than 0.05.

The independent variables in this research work are patch width, patch length, width of substrate and height of substrate. Gain, bandwidth and VSWR are the dependent variables. Gain in dB, bandwidth in GHz and VSWR are noted from simulation results.

3. Results

Figure 1 gives the flowchart for testing procedure of an Antenna using FEKO tool. Fig. 2, Fig. 3 and Fig. 4 shows the T-shaped slot microstrip patch antenna and the U-shaped slot microstrip patch antenna was designed and simulated by using the FEKO tool.

Fig. 1 - Flowchart for Testing Procedure of an Antenna Using FEKO Tool
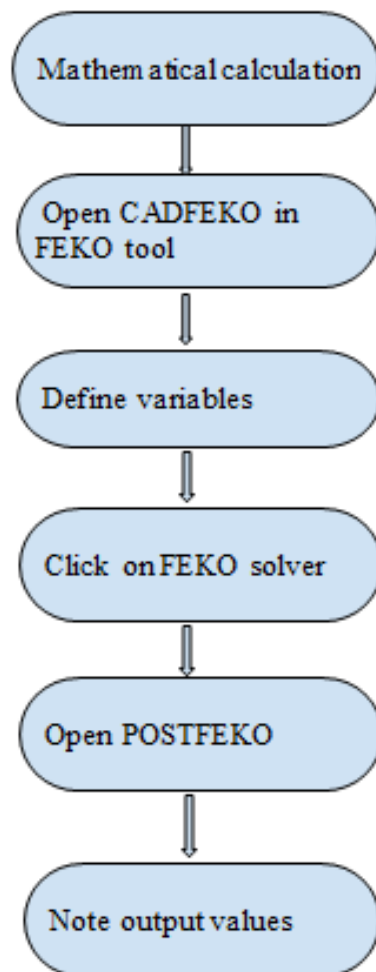
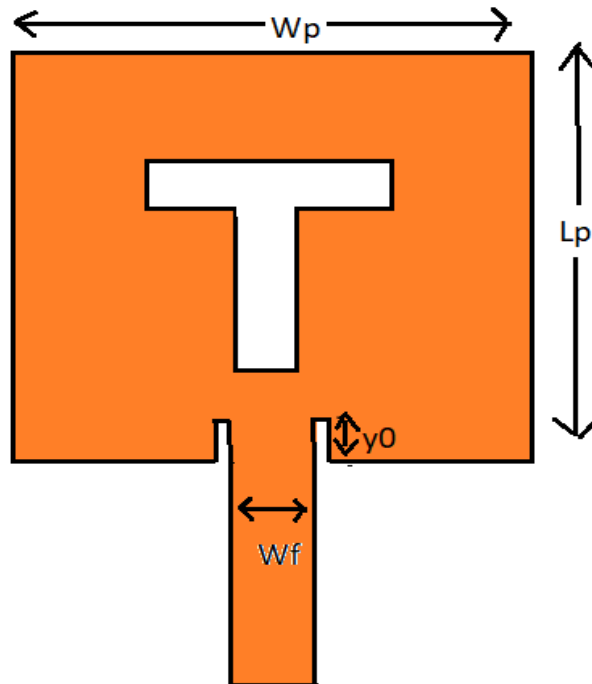Fig. 2 - T-shaped Slot Microstrip Patch Antenna Using FR4 Material

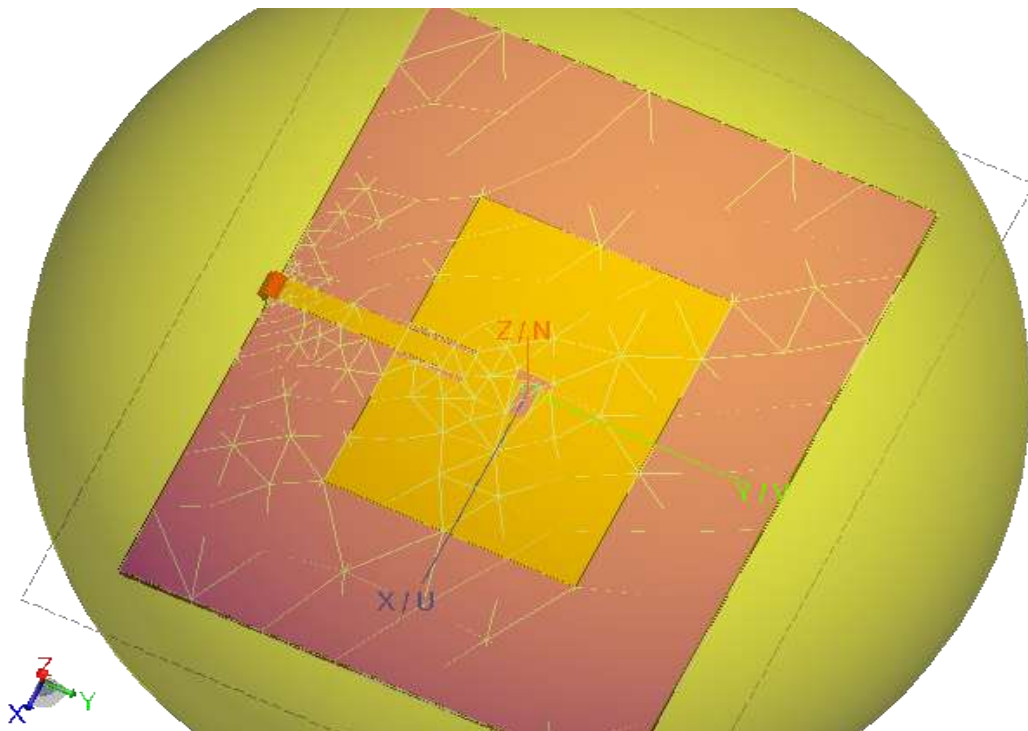Fig. 3 - 3D View of T-shaped Slot Microstrip Patch Antenna Using FR4 Substrate in FEKO Tool

Fig. 4 - 3D View of U-shaped Slot Microstrip Patch Antenna Using FR4 Substrate in FEKO Tool
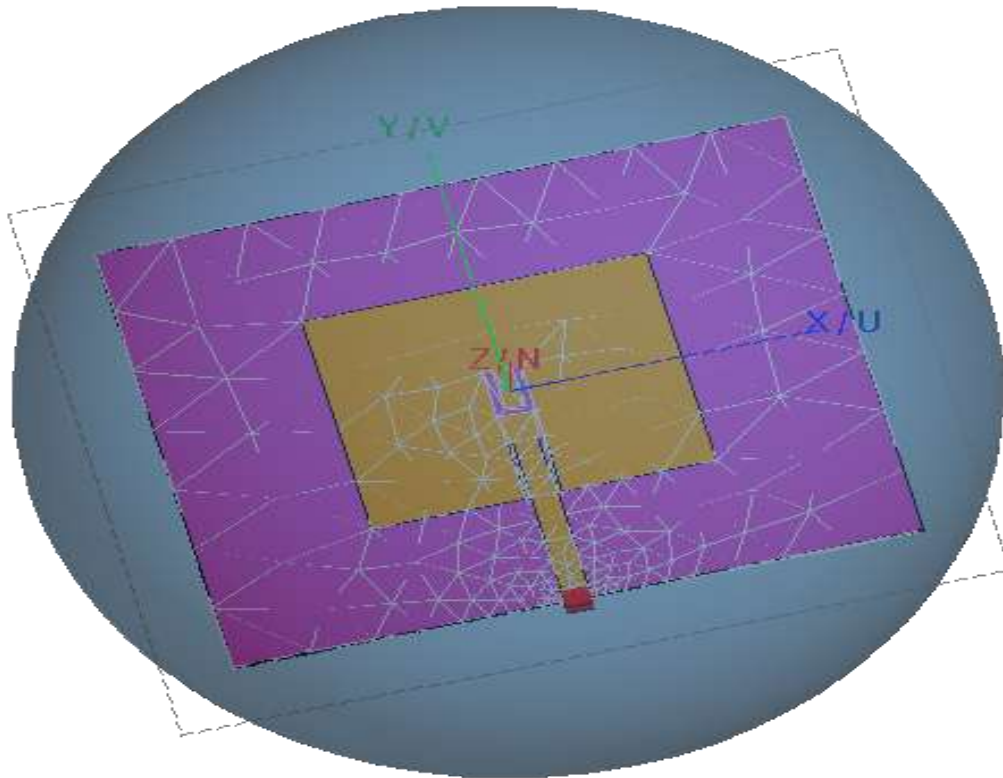

Figure 5 shows the Peak gain of an antenna having 4 dB. If there is a change in frequency the gain changes. Fig. 6 shows the Cartesian representation of an T-shape and U-shape slot antennas having the bandwidth. If the thickness of substrate is high then bandwidth will increase. It is observed that a T-shaped slot antenna exhibits higher bandwidth compared to a U-shaped slot antenna.

Fig. 5 - 3D Polar Plot of Gain of T-shape Slot Microstrip Patch Antenna shows Peak gain as 4 dBi. The Color Representations the Range of Gain from Minimum to Maximum
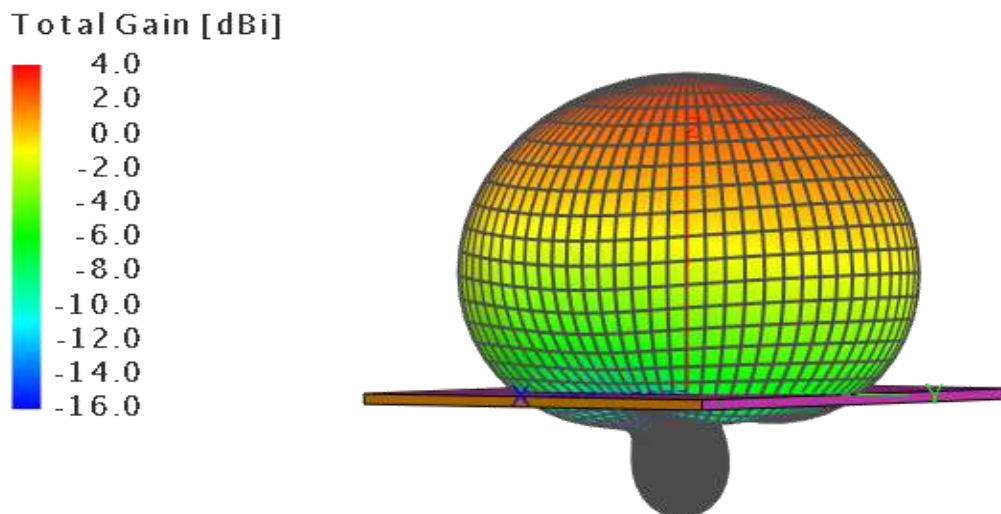
Fig. 6 - U-slot &T-Slot Antennas Bandwidth Comparison Graph. Blue colour represents U-shaped slot microstrip patch antenna and green colour represents T-shaped slot microstrip patch antenna.If the thickness of substrate is high then bandwidth will increase. It is observed that a T-shaped slot antenna exhibits higher bandwidth compared to a U-shaped slot antenna
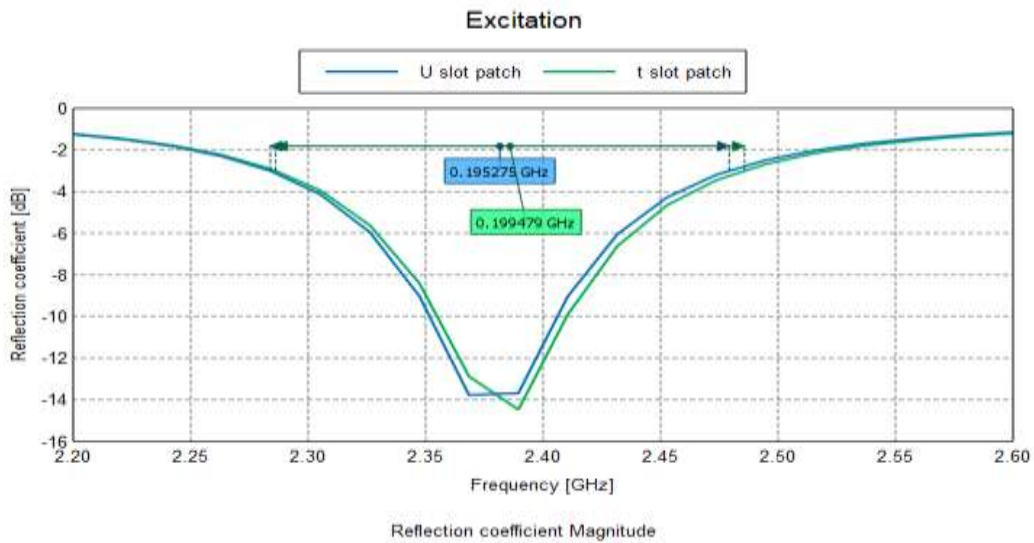

Figure 7 shows the gain of an T-shape and U-shape slot antennas. Antenna gain depends on the size of antenna and wavelength. As designed antenna size is very small, so gain of an antenna is high. T-shaped slot antenna appears to have higher gain than a U-shaped slot antenna. Fig. 8 shows the VSWR values of T-shaped slot antenna and U-shaped slot antenna. It was observed that the T-shape antenna appears to have a lower VSWR than U-shape antenna because as the frequency increases, VSWR decreases up to one point and then increases.

Fig. 7 - U&T shaped Slot antennas gain comparison graph Blue curve represents the T-shaped slot antenna and the green curve represents the U-shaped slot antenna. Gain of an antenna depends on the size of antenna and wavelength. Designed antenna size is very small, so gain of an antenna is high. T-shaped slot antenna appears to have higher gain than a U-shaped slot antenna.
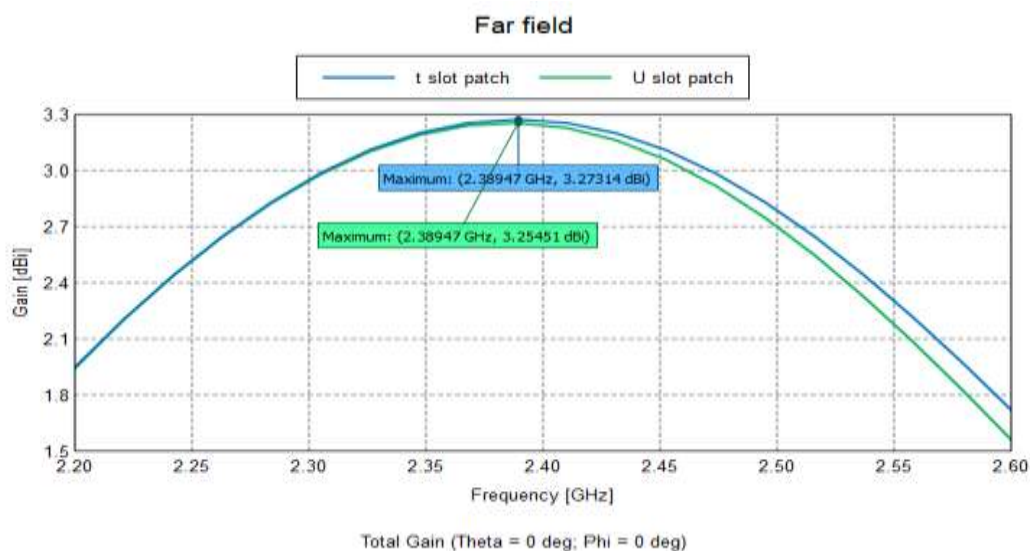
Fig. 8 - U&T shaped Slot antennas VSWR comparison graph Blue curve represents the T-shaped slot microstrip patch antenna and green curve represents the U-shaped slot microstrip patch antenna. It shows T-shape appears to have lower VSWR than U-shape. VSWR decreases upto one point and then increases.
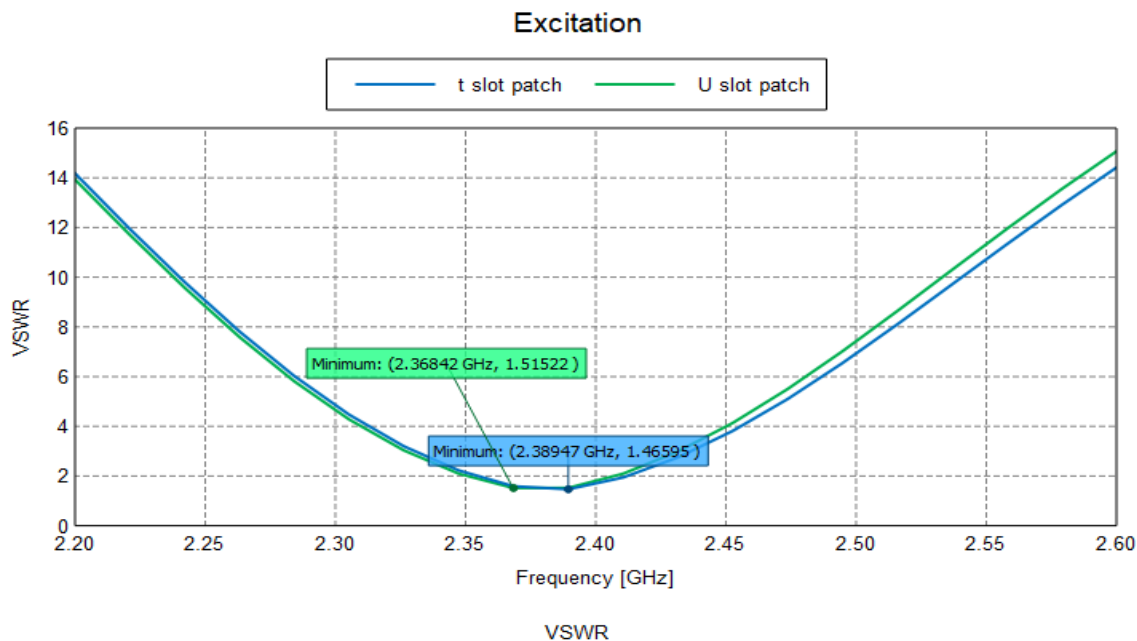
Figure 9 shows that T-shape slot antennas have higher mean gain and VSWR than the U-shape slot antennas. This bar graph obtained from SPSS software.

Fig. 9 - Comparison of U-shape and T-shaped slot antenna in terms of mean. T-shape slot antennas have higher mean gain than the U-shape slot antenna. The T -shape slot antennas have higher VSWR than the U-shape slot antennas. The Mean accuracy of T shape antenna is better than U shape slot antenna.X axis : U shaped and T shaped slot antenna Y Axis : Mean of gain and VSWR of +/- 1 SD
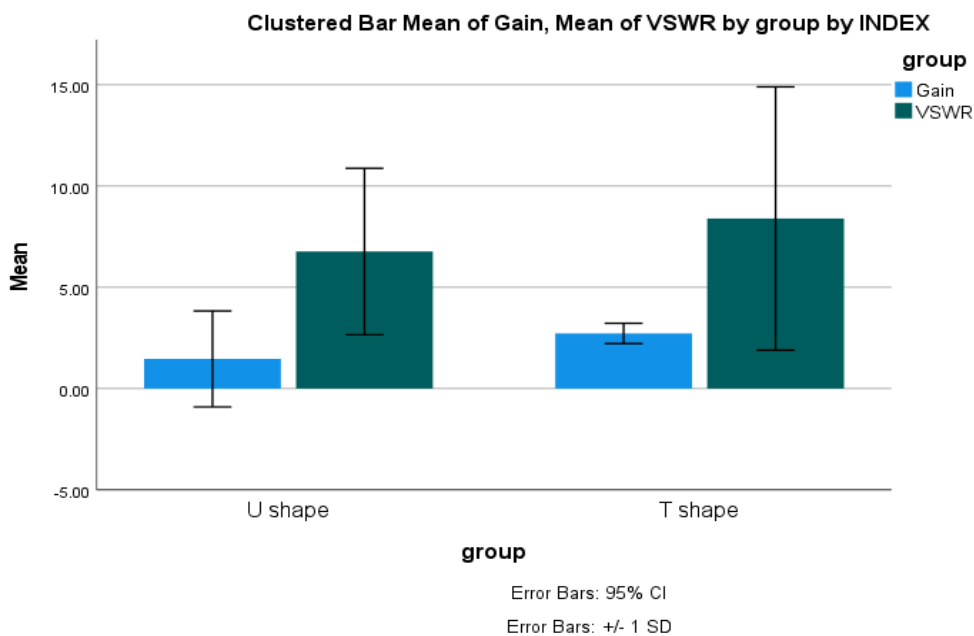
Table 1 gives the Dimensions of an T-shaped and U-shaped antenna using FR4 Material used for designing the antenna in CADFEKO tool and it was calculated by using the formulas. Table 2 gives the Gain and VSWR values for U-shaped slot microstrip patch antenna within frequency range 2.2-2.6 GHz. It was observed that the maximum gain was obtained as 3.25dB and minimum VSWR was obtained as 1.52 at 2.389 (GHz) frequency.

Table 1 - Dimensions of an T-shaped and U-shaped Antenna Using FR4 Material Used for Designing the Antenna in CADFEKO Tool

Dimensions	Value(mm)
w_f	2.8
w_p	36.22
Y_0	7.5
l_p	28.01
h	1.6
ϵ_r	4.4

Table 2 - Gain and VSWR Values for U-shaped Slot Antenna Using FR4 Substrate. Maximum Gain 3.25dB and Minimum VSWR 1.52 are Obtained at 2.389 Frequency

Frequency(GHz)	Gain(dB)	VSWR
2.2	1.94	10.93
2.23	2.31	10.09
2.2406	2.42	9.73
2.25	2.52	8.80
2.2705	2.71	7.01
2.2805	2.80	6.13
2.3002	2.95	4.65
2.311	3.12	2.83
2.368	3.24	1.52
2.389	3.25	1.52
2.4	3.24	1.82
2.418	3.20	2.42
2.431	3.16	2.96
2.45	3.07	4.00
2.4704	-2.94	5.28
2.5	-2.70	7.42
2.52	-2.50	8.97
2.54	-2.29	10.58
2.58	-1.81	13.60
2.6	-1.56	15.10

Table 3 gives the Gain and VSWR for T-shaped slot antennas within frequency range 2.2-2.6 GHz. It was observed that the maximum gain was obtained as 3.31dB and minimum VSWR was obtained as 1.46 at 2.38 (GHz) frequency.

Table 3 - Gain and VSWR Values for T-shaped Slot Antenna Using FR4 substrate. Maximum gain 3.31dB and minimum VSWR 1.46 are obtained at 2.38 GHz frequency

Frequency(GHz)	Gain(dB)	VSWR
2.2	1.92	21.20
2.23	2.28	19.02
2.2406	2.40	18.20
2.25	2.50	17.20
2.2705	2.70	7.00
2.2805	2.79	6.34
2.3002	2.95	4.85
2.311	3.03	2.99
2.368	3.29	1.59
2.389	3.31	1.46
2.4	3.31	1.71
2.418	3.29	2.23
2.431	3.26	2.73
2.45	3.18	3.69
2.4704	3.06	4.89
2.5	2.39	6.93
2.52	2.66	8.43
2.54	2.45	9.98
2.58	1.99	13.00
2.6	1.75	14.40

Table 4 gives the band width of an U shape and T shaped slot antenna having 0.19528 and 0.19948 respectively at operating frequency of 2.389. it was observed that the T-shape appears to have higher bandwidth than U-shape.

Table 4 - Bandwidth values of U-shape and T-shape. The bandwidth of U-shape slot antenna is 0.19528 and T-shape slot antenna is 0.19948 at operating frequency of 2.389. T-shape appears to have higher bandwidth than U-shape

Shape	Frequency(GHz)	Bandwidth(GHz)
U-Shape	2.389	0.19528
T-Shape	2.389	0.19948

Table 5 shows the comparison of bandwidth, gain and VSWR values of U&T slot antennas at 2.389GHz frequency. Bandwidth, gain and VSWR values of the T-shaped slot antenna are 0.19947, 3.2731 and 1.4659 and bandwidth of U-shape slot antenna is 0.19527, gain is 3.2545 and VSWR is 1.5152. From the results obtained, it is clear that the gain and bandwidth of T-shape slot antenna are higher compared to U -shape slot antenna.

Table 5 - Comparison of Bandwidth, gain and VSWR values of U&T shaped slot antennas the gain and bandwidth of T-shape slot are higher compared to U -shape slot antenna

Type of Antenna	Frequency (GHz)	Bandwidth (GHz)	Gain (dB)	VSWR
U-Shape slot Antenna	2.389	0.19527	3.2545	1.5152
T-Shape slot Antenna	2.389	0.19947	3.31	1.4659

Table 6 describes the statistically significant difference between the gain and VSWR of T-shaped slot antenna and U-shaped slot antenna. Mean gain value of U-shape is 1.4626 and VSWR is 6.7675.Mean gain value of T-shape is 2.7238 and VSWR is 8.3951. The mean values of T-shape are higher than the mean values of U-shape.

Table 6 - T test analysis of Mean and standard deviation of U-shape and T-shape parameters. Mean gain value of U-shape is 1.4626 and VSWR is 6.7675. Mean gain value of T-shape is 2.7238 and VSWR is 8.3951. The mean values of T-shape are higher than the mean values of U-shape

	Group	N	Mean	Standard deviation	Standard error mean
Gain	U shape	20	1.4626	2.36819	0.52954
	T shape	20	2.7238	0.49882	0.1114
VSWR	U shape	20	6.7675	4.10712	0.91838
	T shape	20	8.3951	6.50182	1.45385

Table 7 shows the significance values. The significance value of gain is <0.001 and VSWR is 0.031. The obtained significance values are less than 0.05. That means the error percentage is less than 5% (sig.<0.05).

Table 7 - Significance values of gain and VSWR. The significance value of gain is <0.001 and VSWR is 0.031. The obtained significance values are less than 0.05. That means the error percentage is less than 5% (sig.<0.05)

		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	28.683	<0.001	-2.330	38	0.025	-1.26117	0.54116	-2.35670	-0.16565
	Equal variances not assumed			-2.330	20.683	0.030	-1.26117	0.54116	-2.35664	-0.13471
VSWR	Equal variances assumed	4.996	0.031	-0.947	38	0.350	-1.62764	1.71962	-5.10883	1.85358
	Equal variances not assumed			-0.947	32.080	0.351	-1.62764	1.71962	-5.13005	1.874771

4. Discussion

Performance parameters of T-shaped slot microstrip patch antenna are higher compared to U-shaped slot microstrip patch antenna. Sample size of this research work is 40.

As the thickness of substrate of T-shape and U-shape patch antenna increases and size decreases,then the bandwidth and gain increases("Metamaterials and Metasurfaces" n.d.) ("Bandwidth Enhancement of Printed E-Shaped Slot Antennas Fed by CPW and Microstrip Line" n.d.). As frequency increases from 2.2-2.6 GHz VSWR decreases upto one point and then increases and gain increases upto one point and then decreases.

Factors affecting the VSWR are reflection coefficient(s11), shape of slot and length(Tianang, Elmansouri, and Filipovic 2018). If the VSWR value of an antenna is smaller than 2(VSWR<2), it means that antenna matched perfectly with the transmission line(Sunthari, Mohana Sunthari, and Veeramani 2017).Factors affecting the bandwidth and gain of T-shape and U-shape are thickness of FR4 substrate, size of antenna and feeding technique.

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.

Considering the limitation of this research work as applications restricted to only limited distance, future scope of this work can be designing microstrip patch antennas with different shapes of slots for enhancing the bandwidth, gain. By changing the substrate, flexibility of an antenna will increase. Flexibility is a vital aspect for health monitoring systems.

5. Conclusion

It is observed that bandwidth and gain of T-shaped slot Innovative microstrip patch antenna are higher compared to U-shaped slot microstrip patch antenna. VSWR of T-shaped slot microstrip patch antenna is smaller compared to U-shaped slot microstrip patch antenna. FR4 material is used as a substrate for designing antennas. Wearable T-shaped slot microstrip patch antenna is designed and simulated by using FEKO tool. Due to its high bandwidth this antenna can be used in health monitoring systems. This antenna can be used for long distance communication. Simulation results show that, T-shape slot antenna having high bandwidth(0.19947 GHz), high gain(3.31dB) and low

VSWR(1.46) compared to U-shaped slot antenna(bandwidth=0.19527 GHz, gain=3.25dB and VSWR=1.52).

Declarations

Conflict of interests

No conflict of interests in this manuscript.

Authors Contributions

Author Mannem Meghana was involved in data collection, data analysis, manuscript writing. Author Bhaskarrao Yakkala was involved in conceptualization, data validation, and critical review of manuscript.

Acknowledgments

References

Dastranj, A., & Abiri, H. (2010). Bandwidth enhancement of printed E-shaped slot antennas fed by CPW and microstrip line. *IEEE Transactions on Antennas and Propagation*, *58*(4), 1402-1407.

Corchia, L., Monti, G., De Benedetto, E., & Tarricone, L. (2017). Wearable antennas for remote health care monitoring systems. *International Journal of Antennas and Propagation*, *2017*. https://doi.org/10.1155/2017/3012341.

Dhayabarani, R., Anitha, C., John, J. A., Gomathi, P., & Hebsiba, B. (2018). High Gain Microstrip patch Antenna for Biomedical Applications. *In Second International Conference on Inventive Communication and Computational Technologies (ICICCT),* 1201-1204.

https://doi.org/10.1109/icicct.2018.8473247.

Ezhilarasan, D., Apoorva, V. S., & Ashok Vardhan, N. (2019). Syzygium cumini extract induced reactive oxygen species-mediated apoptosis in human oral squamous carcinoma cells. *Journal of Oral Pathology & Medicine*, *48*(2), 115-121.

Gheena, S., & Ezhilarasan, D. (2019). Syringic acid triggers reactive oxygen species–mediated cytotoxicity in HepG2 cells. *Human & experimental toxicology*, *38*(6), 694-702.

Green, R. B., Toporkov, M., Ullah, M. D. B., Avrutin, V., Ozgur, U., Morkoc, H., & Topsakal, E. (2017). An alternative material for transparent antennas for commercial and medical applications. *Microwave and Optical Technology Letters, 59*(4), 773-777. https://doi.org/10.1002/mop.30404.

Jose, J., & Subbaiyan, H. (2020). Different treatment modalities followed by dental practitioners for ellis class 2 fracture–A questionnaire-based survey. *The Open Dentistry Journal*, *14*(1), 59–65.

Ke, Y., Al Aboody, M.S., Alturaiki, W., Alsagaby, S.A., Alfaiz, F.A., Veeraraghavan, V.P., & Mickymaray, S. (2019). Photosynthesized gold nanoparticles from Catharanthus roseus induces caspase-mediated apoptosis in cervical cancer cells (HeLa). *Artificial cells, nanomedicine, and biotechnology*, *47*(1), 1938-1946.

Krishnaswamy, H., Muthukrishnan, S., Thanikodi, S., Antony, G.A., & Venkatraman, V. (2020). Investigation of air conditioning temperature variation by modifying the structure of passenger car using computational fluid dynamics. *Thermal Science*, *24*(1 Part B), 495-498.

Kumar, A., Badhai, R.K., & Suraj, P. (2018). Design of a printed symmetrical CPW-fed monopole antenna for on-body medical diagnosis applications. *Journal of Computational Electronics*, *17*(4), 1741-1747.

Latif, A. (2020). Design of a UWB Coplanar Fed Antenna and Circular Miniature Printed Antenna for Medical Applications. *In Advanced Radio Frequency Antennas for Modern Communication and Medical Systems*. IntechOpen. https://doi.org/10.5772/intechopen.93205.

Malli Sureshbabu, N., Selvarasu, K., Nandakumar, M., & Selvam, D. (2019). Concentrated growth factors as an ingenious biomaterial in regeneration of bony defects after periapical surgery: A report of two cases. *Case reports in dentistry*, *2019*.

Mathew, M.G., Samuel, S.R., Soni, A.J., & Roopa, K.B. (2020). Evaluation of adhesion of Streptococcus mutans, plaque accumulation on zirconia and stainless steel crowns, and surrounding gingival inflammation in primary molars: Randomized controlled trial. *Clinical oral investigations*, *24*(9), 3275-3280.

Mehta, M., Tewari, D., Gupta, G., Awasthi, R., Singh, H., Pandey, P., & Satija, S. (2019). Oligonucleotide therapy: an emerging focus area for drug delivery in chronic inflammatory respiratory diseases. *Chemico-biological interactions*, *308*, 206-215.

Josep, C. Metamaterials and Metasurfaces.

https://books.google.com/books/about/Metamaterials_and_Metasurfaces.html?id=oC-RDwAAQBAJ

Muthukrishnan, S., Krishnaswamy, H., Thanikodi, S., Sundaresan, D., & Venkatraman, V. (2020). Support vector machine for modelling and simulation of Heat exchangers. *Thermal Science*, *24* (1 Part B), 499-503.

Panda, S., Gupta, A., & Acharya, B. (2021). Wearable microstrip patch antennas with different flexible substrates for health monitoring system. *Materials Today: Proceedings*, *45*(4), 4002-4007. https://doi.org/10.1016/j.matpr.2020.09.127.

PC, J., Marimuthu, T., Devadoss, P., & Kumar, S. M. (2018). Prevalence and measurement of anterior loop of the mandibular canal using CBCT: A cross sectional study. *Clinical implant dentistry and related research*, *20*(4), 531-534. https://europepmc.org/article/med/29624863.

Raju, M.P., Kishore, D.P., & Madhav, B.T.P. (2019). CPW Fed T-shaped wearable antenna for ISM Band, Wi-Fi, WiMAX, WLAN and fixed satellite service applications. *Journal of Electromagnetic Engineering and Science*, *19*(2), 140-146. https://doi.org/10.26866/jees.2019.19.2.140.

Ramadurai, N., Gurunathan, D., Samuel, A.V., Subramanian, E., & Rodrigues, S.J. (2019). Effectiveness of 2% Articaine as an anesthetic agent in children: randomized controlled trial. *Clinical oral investigations*, *23*(9), 3543-3550.

Ramesh, A., Varghese, S., Jayakumar, N.D., & Malaiappan, S. (2018). Comparative estimation of sulfiredoxin levels between chronic periodontitis and healthy patients–A case-control study. *Journal of periodontology*, *89*(10), 1241-1248.

Samuel, M.S., Bhattacharya, J., Raj, S., Santhanam, N., Singh, H., & Singh, N.P. (2019). Efficient removal of Chromium (VI) from aqueous solution using chitosan grafted graphene oxide (CS-GO) nanocomposite. *International journal of biological macromolecules*, *121*, 285-292.

Samuel, S.R., Acharya, S., & Rao, J.C. (2020). School Interventions–based Prevention of Early-Childhood Caries among 3–5-year-old children from very low socioeconomic status: Two-year randomized trial. *Journal of public health dentistry*, *80*(1), 51-60.

Sathish, T., & Karthick, S. (2020). Wear behaviour analysis on aluminium alloy 7050 with reinforced SiC through taguchi approach. *Journal of Materials Research and Technology*, *9*(3), 3481-3487.

Shanwar, A.R., & Othman, N.S. (2017). UWB printed antenna for medical applications. *In TENCON 2017-2017 IEEE Region 10 Conference*, 2931-2936. https://doi.org/10.1109/tencon.2017.8228364.

Sharma, P., Mehta, M., Dhanjal, D.S., Kaur, S., Gupta, G., Singh, H., & Satija, S. (2019). Emerging trends in the novel drug delivery approaches for the treatment of lung cancer. *Chemico-biological interactions*, *309*, 108720.

Singh, D., Thakur, A., & Srivastava, V.M. (2018). Miniaturization and Gain Enhancement of Microstrip Patch Antenna Using Defected Ground with EBG. *Journal of Communication*, *13*(12), 730-736. https://doi.org/10.12720/jcm.13.12.730-736.

Sreelakshmy, R., Ashok Kumar, S., & Shanmuganantham, T. (2017). A wearable type embroidered logo antenna at ISM band for military applications. *Microwave and Optical Technology Letters*, *59*(9), 2159-2163. https://doi.org/10.1002/mop.30697.

Sridharan, G., Ramani, P., Patankar, S., & Vijayaraghavan, R. (2019). Evaluation of salivary metabolomics in oral leukoplakia and oral squamous cell carcinoma. *Journal of Oral Pathology & Medicine*, *48*(4), 299-306.

Sukhija, S., & Sarin, R.K. (2017). A U-shaped meandered slot antenna for biomedical applications. *Progress in Electromagnetics Research, 62*, 65-77. https://doi.org/10.2528/pierm17082101.

Sukhija, S., & Sarin, R.K. (2017). Low-profile patch antennas for biomedical and wireless applications. *Journal of Computational Electronics*, *16*(2), 354-368.

Sunthari, P.M., & Veeramani, R. (2017). Multiband microstrip patch antenna for 5G wireless applications using MIMO techniques. *In First International Conference on Recent Advances in Aerospace Engineering (ICRAAE)*, 1-5. https://doi.org/10.1109/icraae.2017.8297241.

Tianang, E.G., Mohamed A.E., & Dejan, S.F. (2018). Ultra-Wideband Lossless Cavity-Backed Vivaldi Antenna. *IEEE Transactions on Antennas and Propagation*, *66*(1), 115-124. https://doi.org/10.1109/tap.2017.2775286.

Varghese, S.S., Ramesh, A., & Veeraiyan, D.N. (2019). Blended Module-Based Teaching in Biostatistics and Research Methodology: A Retrospective Study with Postgraduate Dental Students. *Journal of dental education*, *83*(4), 445-450.

Venu, H., Raju, V.D., & Subramani, L. (2019). Combined effect of influence of nano additives, combustion chamber geometry and injection timing in a DI diesel engine fuelled with ternary (diesel-biodiesel-ethanol) blends. *Energy*, *174*, 386-406.

Venu, H., Subramani, L., & Raju, V.D. (2019). Emission reduction in a DI diesel engine using exhaust gas recirculation (EGR) of palm biodiesel blended with TiO2 nano additives. *Renewable Energy*, *140*, 245-263.

Vignesh, R., Ditto Sharmin, C., Annamalai, S., & Baghkomeh, P.N. (2019). Management of complicated crown-root fracture by extra-oral fragment reattachment and intentional reimplantation with 2 years review. *Contemporary clinical dentistry, 10*(2), 397-401.

Jain, S.V., Muthusekhar, M.R., Baig, M.F., Senthilnathan, P., Loganathan, S., Wahab, P.A., & Vohra, Y. (2019). Evaluation of three-dimensional changes in pharyngeal airway following isolated lefort one osteotomy for the correction of vertical maxillary excess: a prospective study. *Journal of maxillofacial and oral surgery*, *18*(1), 139-146.

Vijayashree Priyadharsini, J. (2019). In silico validation of the non-antibiotic drugs acetaminophen and ibuprofen as antibacterial agents against red complex pathogens. *Journal of periodontology*, *90*(12), 1441-1448.