I.J. Wireless and Microwave Technologies, **2024, 2, 65-74**
Published Online on April 8, 2024 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijwmt.2024.02.05

Surface Fitting Based Modelling of a Circular Microstrip Patch Antenna Operating at 3 GHz Frequency

Asanka Maiti
Department of Department of Electronics and Communication Engineering, Jalpaiguri Government Engineering College, Jalpaiguri, PIN-735102, India
Email: asankamaiti111@gmail.com
ORCID iD: https://orcid.org//0009-0009-0619-2342

Sudip Mandal*
Department of Department of Electronics and Communication Engineering, Jalpaiguri Government Engineering College, Jalpaiguri, PIN-735102, India
Email: sudip.mandal007@gmail.com
ORCID iD: https://orcid.org//0000-0002-7444-3942
*Corresponding Author

Received: 07 January, 2024; Revised: 31 January, 2024; Accepted: 22 February, 2024; Published: 08 April, 2024

Abstract: Designing a microstrip patch antenna at 3GHz frequency is very interesting task to the researchers due to wide applicability for IoT, body wearable antenna, WLAN, ISM communication etc. In this paper, a circular microstrip patch antenna with resonance at a frequency of 3GHz has been designed using FR4 substrate and inset feeding using CST studio. Initially, the antenna is manually tuned at the 3GHz operating frequency and obtain S_{11} is -38dB which is best compare to the existing works at this frequency. Next, the parametric influences have been observed by varying several antenna design parameters (i.e. patch radius and substrate height) and observing the respective variation in output like S_{11}, bandwidth. In the next phase of this work, surface fitting technique has been used to model the 3GHz circular patch antenna that helps to predict the output S_{11}, resonance frequency and bandwidth with satisfactory prediction accuracy. Surface-fitting model will help to reduce the effort and time required for redesigning and simulation of this type of circular patch antenna in future.

Index Terms: Microstrip Patch Antenna, Circular Patch, Surface Fitting, Modelling, 3GHz Frequency, IoT.

1. Introduction

Microstrip antennas have extensively been used in commercial and military communication systems due to their simplicity, conformability, low manufacturing cost, light weight, low profile, reproducibility, reliability, and ease in fabrication and integration with solid-state devices [1].

A Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate [2]. The patch may be in a variety of shapes, but rectangular and circular are the most common because ease of analysis and fabrication, attractive radiation characteristics, especially low cross polarization. The modes that are supported primarily by a circular microstrip patch antenna whose substrate height is small [3].

The use of sub 3 GHz frequencies combined with recent technological advances has resulted in the reach of digital terrestrial radio systems being greatly extended [4]. Key advantages of sub 3 GHz transmission include largely interference-free operation in licensed bands; an inherent long distance capability; and immunity to many atmospheric conditions. Modest infrastructure requirements also result in lower capital and operational costs, leading to a low total cost of ownership. 3 GHz RF frequency has typically some interesting application like IoT applications, body wearable antenna for health monitoring, ISM communication, WLAN, Radar etc. [5, 6, 7, 8, 9] dictating the efficiency and reliability of data transfer between interconnected devices.

Many authors have attempted designing process of MPA at this frequency band. Kavita et al. [5] designed a body wearable rectangular patch antenna operating at 3.8 GHz frequency for jamming application and able to achieve -17dB S_{11} value. Verma et al. [6] designed microstrip Patch Antenna (MPA) array with Defected Ground Structure (DGS) for Internet of Things (IoT) applications at 3 GHz frequency and the value of S_{11} is -19dB. Mouniga et al. [7] have designed microstrip 2x2 wearable antenna array for 2.45GHz ISM application with satisfactory S_{11} of -35dB. Singhal et al. [8] have proposed rectangular microstrip patch antenna design at 3 GHz using probe feed and able reach -26dB of S_{11}. Rahmatia et al. [9] have designed rectangular microstrip antenna working at 3 GHz for radar application which has S_{11} of -17dB. Pandey et al. [10] designed a circular shape microstrip patch antenna for C-band applications. It seems that existing MPA at S-band i.e. 3GHz frequency have comparative lower S_{11}. Hence, designing 3GHz MPA (for IOT applications) with better S_{11} is still open research problem.

In this paper we have designed a circular microstrip patch antenna operating at a frequency of 3GHz. The patch antenna is designed on a FR4. Next, the parametric influences have been observed by varying the antenna design parameters and observing the respective output like S_{11}, bandwidth, resonance frequency etc. CST studio has been used this purpose. In the next phase of this work, surface fitting model has been proposed that helps to predict the output S_{11}, resonance frequency and bandwidth. The results show a promising predicting accuracy. The paper is structure is as follows. In Section 2, methodology for circular patch antenna design is shown. Next, results for the best design 3GHz circular MPA and corresponding surface fitting model has been displayed followed by the conclusion and references.

2. Methodology

The geometry of circular microstrip antenna [9, 10] is shown Fig.1.Circular patch radius is calculated by using the Equation 1 and 2 given below.

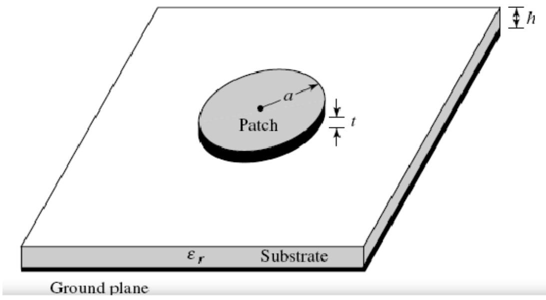

Fig. 1. CST design of proposed antenna

$$a = \frac{F}{\left\{1+\frac{2h}{\pi F \epsilon_r}\left[\ln\left(\frac{\pi F}{2h}\right)\right]+1.7726\right\}^{1/2}} \tag{1}$$

$$F = \frac{8.791\times10^{9}}{f_r\sqrt{\epsilon_r}} \tag{2}$$

where, a is radius of the circular patch, ϵ_r is dielectric constant of substrate, h is height of dielectric substrate, f_r = resonant frequency. The proposed methodology has been consisting of three stages which are described one by one below.

2.1 Schematic and design of microchip patch antenna

In our research, we have designed a circular microstrip patch antenna using the CST Studio [12, 13] antenna design tool, which will work on single band of center frequency 3 GHz using cupper patch and ground plate. For better gain, the substrate is chosen as FR-4 (lossy) with an epsilon value of 4.3. In this case, we have used inset feed method for impedance matching where characteristic impedance is assumed to be 50Ω. Initially, the rough dimensions of the rectangular patch antenna have been calculated using the conventional equations mentioned above with 1mm thick substrate and 0.035mm thick copper patch.

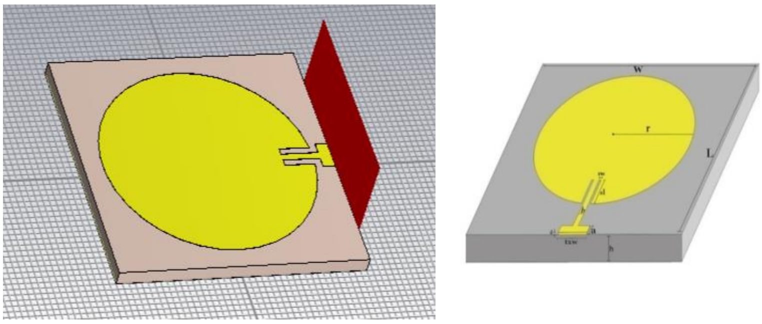

Fig. 2. Schematic of proposed 3 GHz circular patch antenna

Then manual tuning of different dimensions i.e. radius of circular patch and substrate height (h) is done to achieve best performance of the antenna. The outline structure of the proposed antenna is given in Fig. 2. The values of the parameters for the best result after tuning is listed bellow in Table-1.

Table 1. Parameters for the best result of proposed antenna

Sl. No.	Parameter	Value(mm)
1	Antenna Radius (r)	13.95
2	Substrate Height (h)	1.6
3	Substrate Width (w)	40
4	Substrate Length (L)	40
5	Patch depth (d)	0.035
6	Transmission Line Width (txw)	3.13
7	Inset Length (sl)	5
8	Inset Width (sw)	1
9	a	2
10	b	1

2.2 Observation of Parametric Influence

Now, to observe the influence of various circular patch antenna parameters (i.e. radius of the patch , substrate height etc.) on the outputs (i.e. S_{11}, bandwidth etc.), we have changed the parameter values with some specified step variations. Then, we run the simulation for each variation, plotted them together in one graph for easier understanding and observe the influences on the outputs.

2.3 Patch Antenna modeling using Surface Fitting

Next, we develop a mathematical model with which we can predict the values of S_{11}, center frequency and band width using surface fitting technique., if we put the values of antenna radius and substrate height in this model, then we can get the values of S11, center frequency, band width and other parameters automatically without running new simulation.

3. Results and Discussions

In this section, the results corresponding to the proposed methodology are described.

3.1 Outputs of Optimized 3GHz Circular Patch Antenna

By adjusting the different dimensions of the circular patch antenna, initially we have tried to reach the best case i.e. close to the 3GHz frequency with minimum S_{11} value. The respective dimension of the antenna parameters are already given in Table 1.

3.1.1 S_{11} curve for best case scenario:

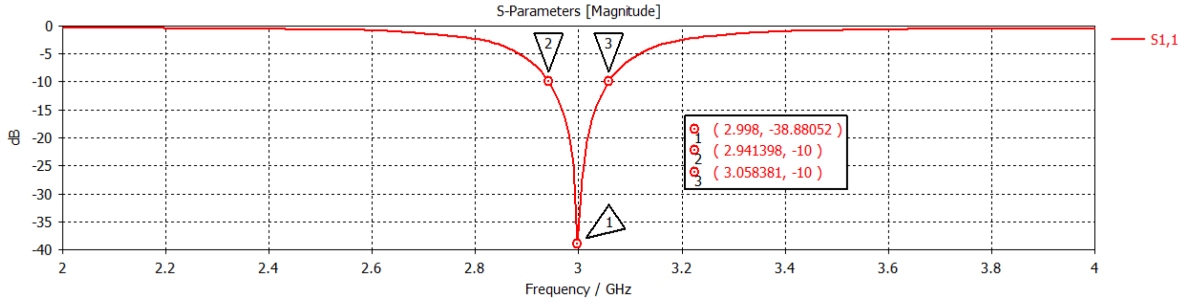

Fig. 3. Variation of S_{11} vs. frequency

Fig. 3 shows the variation of S_{11} value w.r.t. frequency for the proposed antenna design. It has been observed that the proposed antenna resonates at 2.998 GHz frequency and the corresponding S_{11} value is -38.88 dB. The target center frequency of the antenna was 3 GHz and it indicates a very satisfactory finding.

3.1.2 Bandwidth

From Fig. 4, upper frequency and lower frequency (-10 dB less) of the proposed circular patch antenna are found at 3.0584 GHz and 2.9413 GHz respectively. Hence, the bandwidth of the antenna found as (3.0584- 2.9413) GHz = 0.117 1GHz i.e. 117.1 MHz. It is satisfactory for the IoT communication.

3.1.3 Gain

Fig. 4 shows the variation gain of our proposed antenna with respect to its frequency and it has been observed that up to frequency 3GHz (which is our desired center frequency) the gain rises linearly and at 3 GHz freq the gain value is 2.63 dB. After 3GHz frequency the gain remains almost constant.

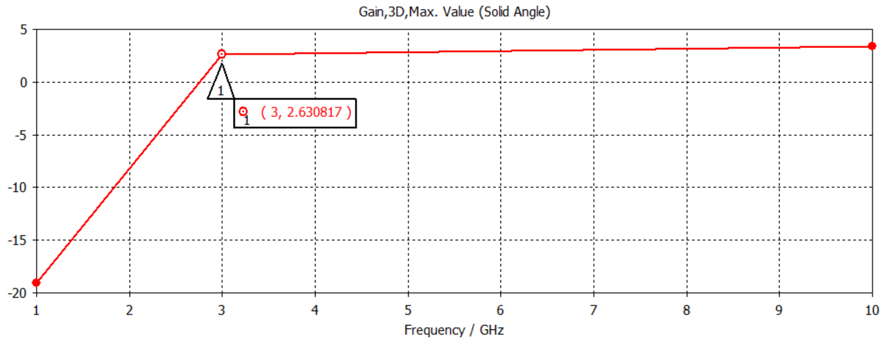

Fig. 4. Variation of gain vs. frequency

3.1.4 VSWR

Fig. 5 shows Voltage Standing Wave Ratio (VSWR) curve. It has been observed that the proposed antenna less reflect at 2.99 GHz frequency and the corresponding VSWR value nearly 1.038 which is very satisfactory results.

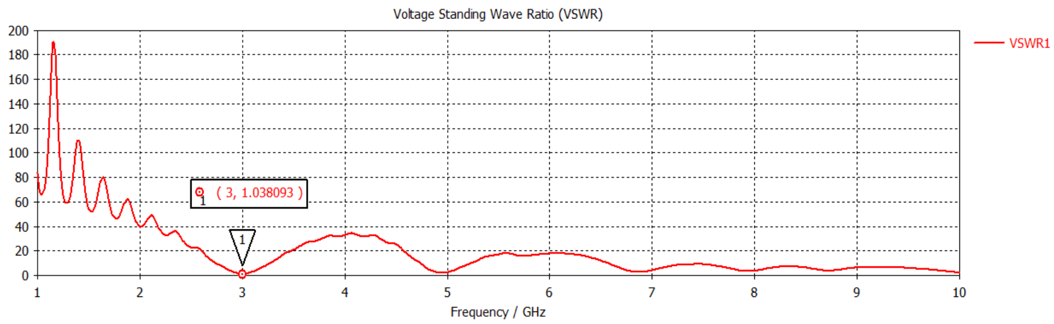

Fig. 5. Variation of VSWR vs. frequency

3.1.5 Impedance

Fig. 6 shows Z-Parameters or Impedance Parameters. We know the antenna radiates maximum power when impedance is 50 Ohm. It has been clearly observed that the Impedance at 2.99 GHz is around 48.9 Ohm.

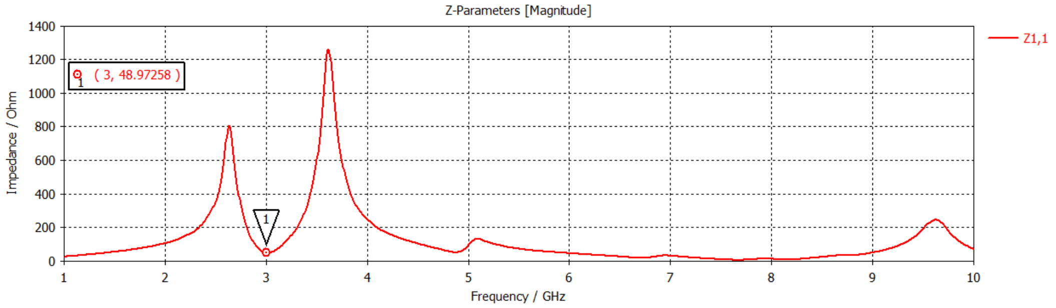

Fig. 6: Variation of impedance wrt frequency

3.1.6 Radiation Pattern

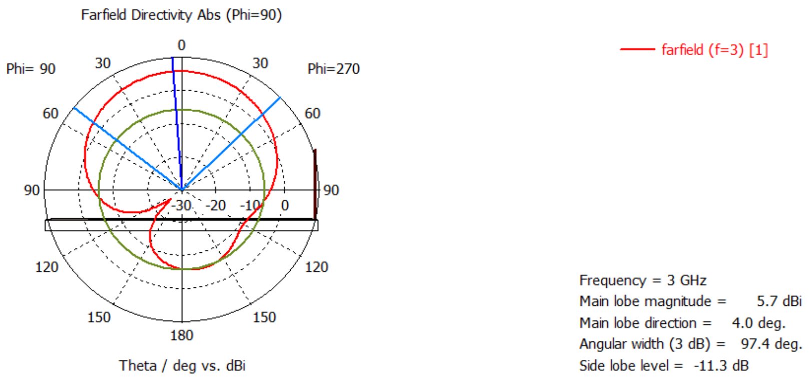

Fig. 7. Radiation pattern of proposed antenna

The above figure shows far field radiation pattern of antenna. It has been observed that the HPBW of the proposed micro strip patch antenna is 97.4 degree which is good for the IoT communication.

3.1.7 Comparative Study

Here, the outputs (i.e. S_{11}, bandwidth, Gain and HPBW) of the proposed 3 GHz circular patch antenna are compared with the similar MPA design works at 3GHz.

Table 2. Comparative study with similar works

Work	S_{11}	Bandwidth	Gain	HPBW
Verma et al. [6]	-18dB	3.0400-2.9800=60MHz	3.98dB	--
Singhal et al. [8]	-26dB	3.0250-2.9550=70MHz	6.48dB	--
Rahmatia et al. [9]	-17dB	--	--	--
Proposed Work	**-38dB**	3.0584- 2.9413=**117.1MHz**	2.63dB	97.4 degree

From the above mentioned table, we can observed that the proposed antenna is superior than other two similar works Verma et al. [6], Singhal et al. [8] and Rahmatia et al. [9] with respect to S_{11} (-38dB) and bandwidth (117.1 MHz). The output are very much suitable for the IoT applications. The best values are shown with bold front. However, the gain of the proposed antenna is slightly less compare to the others techniques. HPBW for others works were not reported.

3.2 Results for Parametric Influences

In our case, we have observed the variation of S_{11} parameter with respect to the frequency for different values of radius of the patch and height of the substrate. While varying one parameter, other parameters are kept unchanged i.e. remained in the same values as mentioned in Table 1. Following two cases are considered.

3.2.1 Variation of Radius

In this case, we have varied the radius of the antenna but other parameters remain same. We took 7 different values of the radius of circular patch by decreasing the value three times with a step difference of 1mm and increasing three times with a step difference of 1 mm from the best value (i.e. 13.95mm). Now, we simulated the antenna in CST Studio for these total 7 values of radius and observed the variation of S11 parameter and plotted the graphs as shown in Fig. 8.

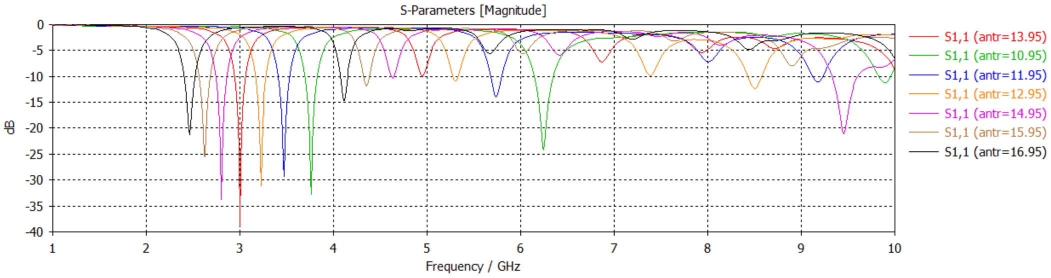

Fig. 8. Influence of radius on S_{11} parameter

From Fig. 8, the best values of S_{11} for the radiuses 10.95mm, 11.95mm, 12.95mm, 13.95mm, 14.95mm, 15.95mm, 16.95 mm we got -33dB, -29dB, -31dB, -38dB, -34dB, -25dB, -21dB respectively. Here we clearly observed that we are getting the best value of S_{11} at radius 13.95mm which is -38dB in 2.998 GHz freq, as expected.

Moreover, we can see that with the increase in antenna radius the frequency at which the S_{11} is minimum is decreasing i.e. the centre or resonance frequency is reducing. It seems that the graph is shifting leftwards with increasing the radius. But, the overall nature of the graph remains almost same i.e. it shows single band nature.

3.2.2 Variation of substrate height

In 2nd case, we have varied the substrate height (h) of the proposed circular patch antenna. We took 7 different values of the substrate depth by decreasing the value three times with a step difference of 0.2 mm and increasing three times with a step difference of 0.2 mm from the best value (i.e. 1.6 mm). For these 7 values of depth, we simulated the antenna in CST Studio and observed the variation of S_{11} parameter and plotted the graphs as shown in Fig. 9.

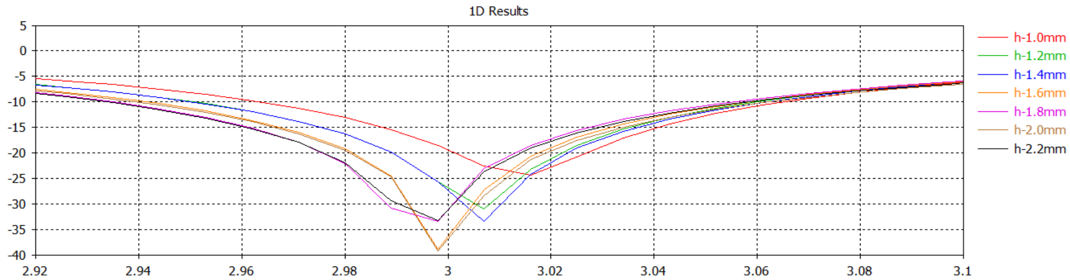

Fig. 9. Influence of substrate height on S11 parameter

From the Fig. 9, the best values of S_{11} for the depths 1.0mm, 1.2mm, 1.4mm, 1.6mm, 1.8mm, 2.0mm, 2.2 mm we got -20dB, -30dB, -34dB, -38dB, -33dB, -37dB, -33 dB respectively. Here, it can be clearly observed that we are getting the best value of S11 at a height 1.6 mm which is -38dB in 2.998 GHz freq, as expected. Moreover, from the above graph we can see that with increasing the value of height up to 1.6mm (best case) the value of S_{11} decreases and after 1.6mm the value of S_{11} increases again.

3.3 Surface Fitting Model of Proposed 3GHz Circular Patch Antenna

For making a mathematical model of the proposed 3GHz circular patch antenna, we have used surface fitting techniques. It will help to predict the output parameters like best S_{11}, resonance frequency, bandwidth with respect to antenna radius and substrate height. We first took 7 different values of antenna radius and 7 different values of substrate height (mentioned in earlier section). For these 49 combinations of the input parameters, we run the simulation and noted the values of S_{11}, center frequency and band width in a tabular form.

Now, with the help of MATLAB surface fitting tool we fitted the values off the respective parameters into a surface. For our precise fitting, we have used *poly 55* i.e. 5 degree polynomial in our curve fitting whose generalized equation is as follows:

$$z(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3 + p40*x^4 + p31*x^3*y+ p22*x^2*y^2 + p13*x*y^3 + p04*y^4 + p50*x^5 + p41*x^4*y + p32*x^3*y^2 + p23*x^2*y^3 + p14*x*y^4 + p05*y^5 \quad (3)$$

Here, x and y are input variable, z is the output parameters, (p00, p10,……………, p55) are respective coefficient of the polynomial.

3.3.1 Modeling of S11

Using surface fitting, we have obtained following polynomial function to fit the best S_{11} parameter with respect to radius (*r*) and depth (*h*) .The coefficients for this surface fitting model is given as:

p00=-34.37, p10=-5.022, p01=-2.015, p20=-0.1512, p11= -3.575, p02=9.471, p30=7.778, p21=7.102, p12=0.3496, p03=2.101, p40= 2.721, p31=-0.8378, p22= -1.982, p13=1.119, p04 = -2.433, p50 = -1.77, p41=-2.178, p32 = -0.8008, p23 =-1.93, p14 = 0.05371, p05 = 0.2544

The obtained surface fitting plot for best S_{11} is shown in Fig. 10.

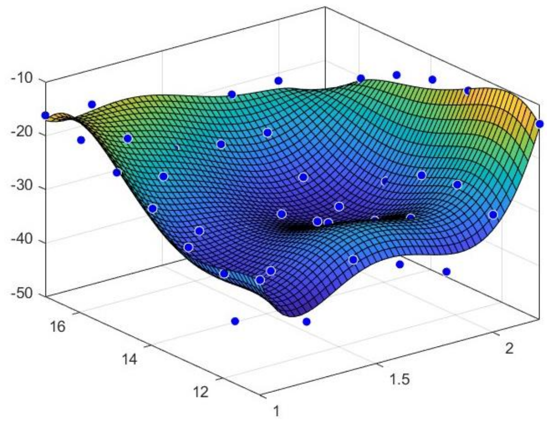

Fig. 10. Surface fitting of S11 w.r.t *r* and *h*

3.3.2 Modeling of Center Frequency

Using surface fitting, we have obtained following polynomial function to fit the center frequency parameter with respect to radius (*r*) and depth (*h*) .The coefficients for this surface fitting model is given as:

p00=3.02, p10=0.03572, p01=-0.4238, p20=-0.1549, p11=0.0231, p02=0.04963, p30= -0.1951, p21=0.01408, p12=-0.007433, p03=-0.004077, p40=0.06854, p31=-0.002829, p22=0.0009783, p13=-0.0004466, p04=0.0009744, p50 =0.08068, p41=-0.005866, p32=0.001705, p23 =0.0001003, p14 = -0.0001231, p05 = -0.001083

The obtained surface fitting plot for center frequency is shown in Fig. 11.

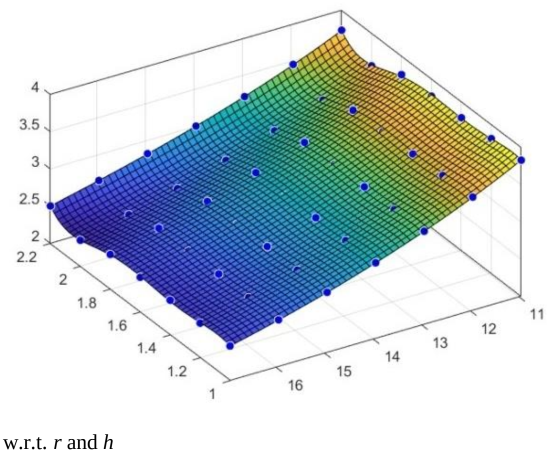

Fig. 11. Surface fitting of center frequency w.r.t. *r* and *h*

3.3.3 Modeling of Bandwidth

Using surface fitting, we have obtained following polynomial function to fit the bandwidth with respect to radius (r) and depth (h) .The coefficients for this surface fitting model is given as:

p00=0.1184, p10=0.01371, p01=0.001316, p20=-0.007077, p11=0.003193, p02=0.00145, p30=-0.01434, p21=-0.004454, p12=0.001338, p03=-0.002809, p40=0.0007651, p31=0.004602, p22=0.0007522, p13=-0.0008618, p04=0.0002301, p50=0.004356, p41=0.003903, p32 =0.0009716, p23= -0.0007699, p14 =-1.322e-05, p05 =0.0001023.

The obtained surface fitting plot for center frequency is shown in Fig. 12.

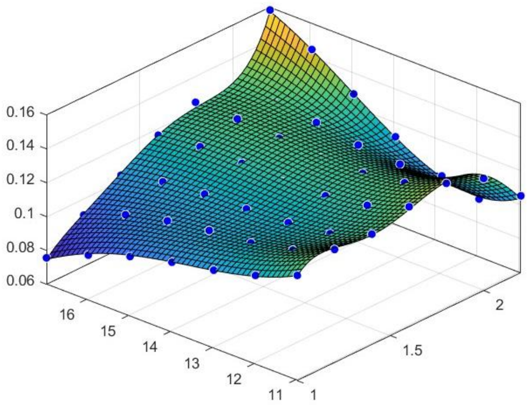

Fig. 12. Surface fitting of center frequency w.r.t. *r* and *h*

3.3.4 Model Validation

Now, to understand how much our curve fitting efficiently works, using the above mentioned equations S_{11}, center frequency, and bandwidth can be calculated or predicted for a set of radius and substrate height. From there, error can be calculated from the difference between predicted and simulated values for all those 49 observations. The error can be defined as using following formula.

$$Error = (Actual\ Value - Predicted\ value) \tag{4}$$

After collecting all simulation results, we putted the values from the simulation to the mentioned equation and got the following result.

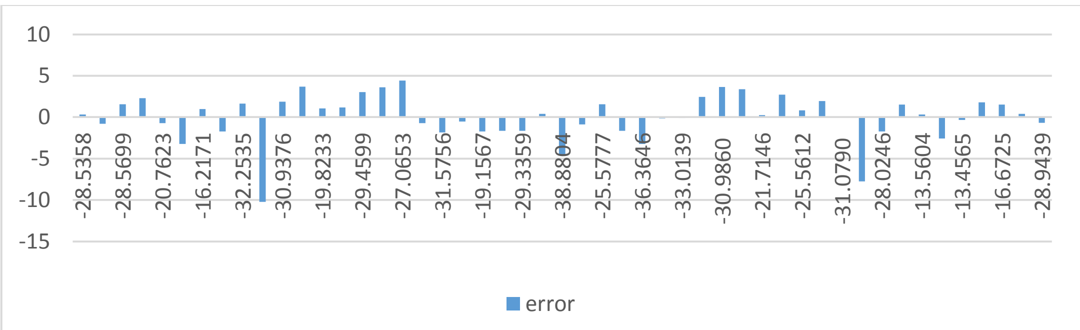

Fig. 13. Variation of S11 error with different observation

From the Fig. 13, we can observe that our surface fitting model for S_{11} works almost satisfactory. But, error is slightly significant where the value of S_{11} is very low.

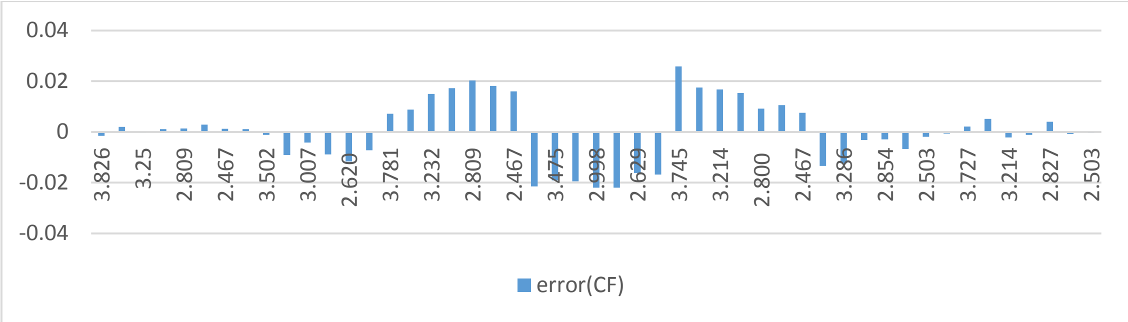

Fig. 14. Variation of Centre Frequency error with different observation

From the Fig. 14 we can see that the errors for the predicted center frequency are very minimal. So, we can say that proposed model works properly.

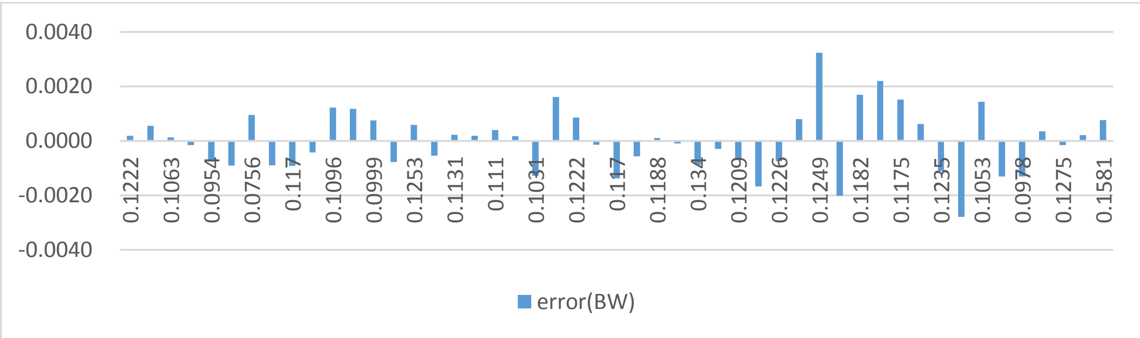

Fig. 15. Variation of Center Frequency error with different observation

From the Fig. 15, we can see that the errors for the bandwidth prediction are very minimal, so we can say our model works properly.

Next, Root Mean Square Error (RMSE) error for each case (S_{11}, center frequency, bandwidth) is determined that indicates the accuracy for prediction of the developed models. The formula for the root mean square error for N observation is

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Actual_{\,i} - Predicted_{\,i})^2}{N}} \tag{5}$$

Table 3. RMSE for different outputs

Parameter	RMSE
S_{11}	2.716899018
Center Frequency	0.001126683
Band Width	0.011906607

RMSE for S_{11}, center frequency, bandwidth are provided in Table 3. It can be observed that RMSE for S_{11} is slightly high. However, the RMSE for center frequency and bandwidth is negligible which indicates that the proposed surface fitting model for the CF and BW works perfectly. It significantly reduces the efforts and time required for the simulation of the circular patch antenna works in this 3GHz frequency band.

4. Conclusion

In this paper, we have designed a circular microstrip patch antenna operating at a frequency of 3 GHz which is suitable for IoT communication. The patch antenna is designed on a substrate FR4 and simulated using CST Studio. The output of the proposed antenna is best with respect to S_{11} and bandwidth compare to the existing works in this frequency band. The output S_{11} (-38dB) and bandwidth (117.1 MHz) are very much suitable for the IoT applications. Next, the parametric influences have been observed by varying the antenna design parameters (i.e. patch radius and substrate depth) and observing the respective output like S_{11}, bandwidth, center frequency.

In the next phase of this work, surface fitting model has been introduced that helps to predict the output S_{11}, resonance frequency and bandwidth. The results show a promising predicting accuracy and it will help to reduce the effort and time required for redesigning and simulation of this type of circular patch antenna.

Conflict of interest: The authors declare that there is no conflict of interest associated with this research.

References

[1] Balanis, Constantine A. *Antenna theory: analysis and design*. John wiley & sons, 2015.

[2] http://www.antenna-theory.com/antennas/patches/antenna.php [access on 07/02/2023]

[3] Singh, Indrasen, and V. S. Tripathi. "Microstrip patch antenna and its applications: a survey." *Int. J. Comp. Tech. Appl* , vol.2, no. 5 (2011): 1595-1599.

[4] Advantages of sub 3 GHz transmission, 4RF, 2012, [www. 4rf.com, accessed on 12/12/2023].

[5] V. Kavitha, I. Ferveez Ahamed, H.Ayma, Body-wearable flexible RF antenna for 3 GHz Jamming applications, *International Journal of Current Engineering And Scientific Research (IJCESR)*, volume-4, issue-11,pp. 16-19, 2017.

[6] Verma, S., Kumar, A. and Agrawal, N., 2023. Design and Optimization of a 3GHz Single Band Patch Antenna Using HFSS: Performance Analysis and Implementation for IoT. *International Journal of Intelligent Systems and Applications in Engineering*, 11(7s), pp.460-465.

[7] J.Mouniga , A.Henridass, Lightweight and Flexible Microstrip 2x2 Wearable Antenna Array for 2.45GHz ISM Application, *International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)*, Volume 23 Issue 2 ,pp. 32-36, 2016

[8] Pallavi Singhal, Kuldeep Jaimini, Rectangular Microstrip Patch Antenna Design At 3 GHz Using Probe Feed. *International Journal of Emerging Technology and Advanced Engineering*, Volume 3, Issue 11, November 2013, pp 421-425.

[9] Rahmatia, S., Fransiska, D.E., Pratama, N.I.H., Wulandari, P. and Samijayani, O.N., 2017, August. Designing dipole antenna for TV application and rectangular microstrip antenna working at 3 GHz for radar application. In 2017 5th International Conference on Cyber and IT Service Management (CITSM) (pp. 1-6). IEEE

[10] Pandey, S. and Markam, K., 2016. Design and analysis of circular shape microstrip patch antenna for C-band applications. *International Journal of Advanced Research in Computer Science & Technology*, *4*(2), pp.169-171.

[11] Daliri, A., Galehdar, A., John, S., Rowe, W. and Ghorbani, K., 2010. Circular microstrip patch antenna strain sensor for wireless structural health monitoring. In *Proceedings of the world congress on engineering* (Vol. 2, p. 1173).

[12] CST Studio Suite, https://edu.3ds.com/en/software/cst-studio-suite-students edition [Accessed on 05/03/2022].

[13] Nayak, A., Dutta, S., and Mandal S., "Design of Dual Band Microstrip Patch Antenna for 5G Communication Operating at 28 GHz and 46 GHz", *International Journal of Wireless and Microwave Technologies,* Vol.13, No.2, pp. 43-52, 2023.

Authors' Profiles

Asanka Maiti is persuing B.Tech. in Electronics and Communication Engineering from Jalpaiguri Government Engineering College, India and will complete his degreee in 2025. His main research interests consist of Antenna and Communication.

Dr. Sudip Mandal received his PhD degree from the Department of Computer Science and Engineering, University of Calcutta, India in 2019. He received his B.Tech. and M.Tech. in Electronics and Communication Engineering from Kalyani Government Engineering College, India in 2009 and 2011, respectively. Currently, he is working as the Assistant Professor of Electronics and Communication Engineering Department, Jalpaiguri Government Engineering College, Jalpaiguri, India. He was the former Head of ECE Department, Global Institute of Management Technology, Krishnagar, India from 2011 to 2018. His current research interests include antenna design, computational biology, tomography, artificial intelligence and optimization. He is a member of the IEEE Computational Intelligence Society. He has 50+ publications in peer-reviewed journals, and in national and international conferences. He also published 2 Indian patents so far. Dr. Mandal has authored 2 Books so far. He is also editorial and review board member of many peer review international journals.

How to cite this paper: Asanka Maiti, Sudip Mandal, "Surface Fitting Based Modelling of a Circular Microstrip Patch Antenna Operating at 3 GHz Frequency", International Journal of Wireless and Microwave Technologies(IJWMT), Vol.14, No.2, pp. 65-74, 2024. DOI:10.5815/ijwmt.2024.02.05