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Research Article

Impact of Feed Point Position on Patch Antenna's Return Loss and Bandwidth for UWB Applications

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Abstract
The demand for compact, lightweight, and high-performance antennas has increased in recent times in the communication industry. Microstrip patch antenna (MPA) becomes a better choice to effectively fulfill these requirements. In this study, hybrid techniques of partial ground plane, slotted patch, and defective ground structure are employed in MPA design to reduce the return loss, good impedance matching, and increased the bandwidth, gain, and efficiency of the antenna. This research demonstrates the impact of altering the feed point position, a crucial phenomenon of antenna design, on the patch antenna and determines the proper feed point location by comparing a minimum return loss (S_{11}) which achieves the highest performance for the designed antenna. High-frequency structure simulator (HFSS) software is used to design and simulate the patch antenna. The operating frequency of the antenna is 6.85 GHz for UWB applications (3.1–10.6 GHz). A FR4 epoxy substrate material with dimensions of 30 mm × 20 mm is used to design the antenna. It has a dielectric constant of 4.4, a thickness of 0.8 mm and a tangent loss of 0.02. Multiple resonant frequencies are observed with different return losses for each feed location. The analysis shows that the finest feeding point is found at the center of the patch (9, 0) with a very low return loss (-28.35 dB), and a high impedance bandwidth (19.7 GHz). The antenna also achieved a gain of 4.46 dB, a directivity of 4.6904 dB, and a radiation efficiency of 95.90%. Hence, the location of the feed point can be considered as an influential factor in the antenna design.

Keywords: patch antenna; return loss; bandwidth; feed point position; HFSS; UWB; FR4; hybrid technique

1. INTRODUCTION

The development of wireless communications and information technology has made multiple chances for improving the effectiveness of present signal transmission and processing systems. This development is a key impetus for the creation of innovative technologies and systems. Wireless communication system requires an antenna, which is used to transmit or receive radio waves. Effective and dependable antennas such as parabolic reflectors, patch antennas, slot antennas, and folded dipole antennas are needed for the new generation of wireless systems. Even though each type of antenna has its own benefits and drawbacks, the signal from an RF system cannot be sent or received properly without an appropriate design of the antenna. In many wireless communication systems, low-profile antennas are required [1].

Microstrip patch antenna (MPA) is one kind of low-profile antennas. It has some desired characteristics such as light-weight, ease of fabrication, flexibility to adapt to curved surfaces, cost-effectiveness, and compatibility with integrated circuit technology. These attractive properties of MPAs have increased their popularity and demand, and more study is being done for better understanding to improve their performance. MPAs can be created in a variety of shapes like square, rectangular, circular, triangular, trapezoidal, elliptical, etc [2]. Microstrip patch antennas have various advantages, but they also have some drawbacks, for instance, low efficiency and power, low gain and restricted bandwidth. Numerous strategies have been studied and developed in an attempt to overcome their bandwidth and gain constraints. The feeding method or feeding point can play a significant role in considerably increasing or decreasing the microstrip patch antenna's functionality [3]. The four feed mechanisms such as microstrip line, coaxial probe, aperture coupling, and proximity coupling are most widely used to feed a microstrip patch antenna [4] [5]. Their properties as well as advantages and limitations are described elsewhere [6]-[8]. When these various feeding systems are used to improve impedance matching at different frequency bands, the effectiveness of several characteristic factors such as radiation pattern, gain, and beam width are

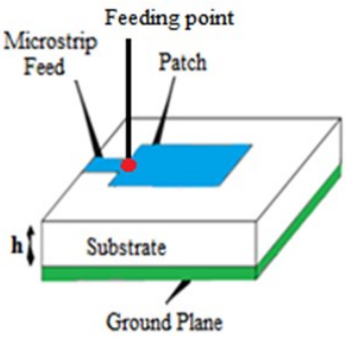

Figure 1. The design of the microstrip line feed.

changed. These factors must be considered whenever a new antenna application needs to be designed [9].

An aperture-coupled feed microstrip patch antenna was developed for the 2.4 GHz frequency band [10][11]. The two feeding methods such as aperture coupled and proximity coupled were used to excite the microstrip patch antenna [12]. Mandal et al. [13] demonstrated that in contrast to aperture-coupled patch antenna, proximity-coupled feed gives considerably greater return loss. It was also studied that the coaxial feedlines provide good impedance matching for designing and analyzing microstrip patch antennas. Matching the impedance between patch and feedline was conducted using coaxial and microstrip line techniques [14]. Several investigations were performed to find the best feed point locations. For instance, the effect of feed location on rectangular microstrip antenna operating at TM_{11} mode was presented in Paul et al [15]. Some investigations were performed to find the proper location for feeding the patch antenna [16]-[18]. A patch antenna made of metamaterials was demonstrated to be influenced by the feed point's position [4]. A study was done to investigate how the feed point position impacts the operating frequency, return loss, and bandwidth of a rectangular microstrip patch antenna and to determine the ideal feed point position [19]-[21]. The effectiveness of a circular patch microstrip antenna was investigated with regard to the impact of feed fluctuation [22].

A T-matching network motivated by metamaterials was directly inserted inside the feedline of a microstrip antenna to accomplish the maximum possible transmission of energy between the front end of an RF wireless transceiver and the antenna [23]. A small, low-profile antenna made of metamaterial unit cells was used to demonstrate high-speed effectiveness for wireless devices through the UHF-SHF bands [24]. An innovative composite right/left-handed (CRLH) metamaterial unit cell-based tiny ultra-wideband (UWB) antenna was developed for modern wireless communication applications [25]. A creative and diminutive nine-element antenna array with a shared aperture structure was described in order to provide substantial gain as well as excellent radiation efficiency at the millimeter-wave 5G band [26]. A novel antenna array with high inter-element isolation was suggested for 5G MIMO communication systems operating at sub-6 GHz [27]. It employed a hybrid strategy that included a flawed ground plane, matching stubs, and dot walls. A hybrid right-left-handed metamaterial transmission line planar antenna's bandwidth and gain were increased by using a non-Foster impedance matching circuit board [28]. Planar antennas were created with implanted slots to increase their bandwidth for reliable multiband RF communications [29]. A novel drifted line loop-based planar broadband antenna was developed for mobile wireless communication devices [30].

However, the majority of these studies [16][17][19]-[21] focus primarily on identifying the best

Table 1. Design Parameters of the proposed antenna.

Parameters	Values (mm)
$W_s = W_g$	20.0
L_s	30.0
h	0.80
W_p	18.0
$L_p = L_g$	14.0
L_f	15.0
$W_f = W_{g1} = W_{p1}$	2.00
L_{g1}	3.00
L_{p1}	8.00
$L_{p5} = L_{p6} = W_{p2} = W_{p3} = W_{p4}$	0.50
$L_{p2} = L_{p3} = L_{p4}$	7.00
$W_{p5} = W_{p6}$	6.50
p = q	6.00
r	8.48

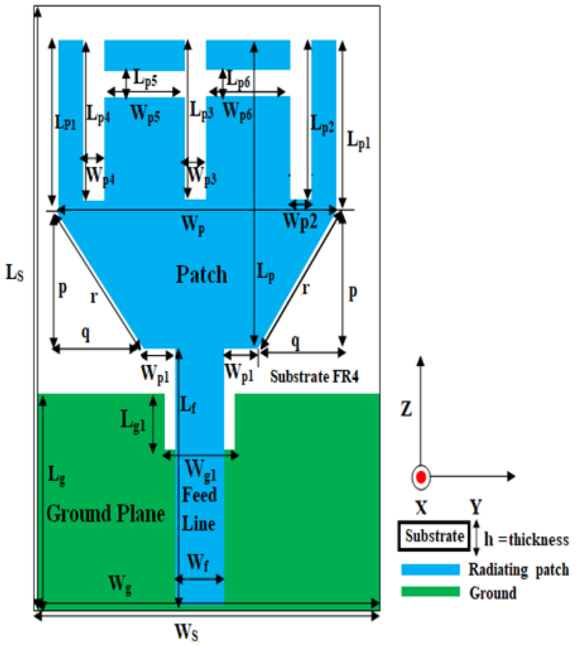

Figure 2. Proposed antenna structure.

feed point, but the key deficiencies of their designed antenna are large antenna size, narrow bandwidth, and limited range of applications. Therefore, a compact rectangular patch antenna is developed for UWB (3.1–10.6 GHz) systems by employing hybrid methodologies (partial ground plane, slotted patch, and defective ground structure) in order to get over from these difficulties. This paper explains how shifting the feed point position implicates the operating frequency, return loss, and impedance bandwidth of the designed antenna. It is also determined the finest feed point location by minimizing the return loss (S_{11}) for suitable applications of the UWB band.

2. MATERIALS AND METHODS

FR4 glass epoxy is widely used due to its good strength-to-weight ratios and ability to operate well under both high and low pressure. It has a 4.4 dielectric constant and a 0.02 tangent loss. FR4 glass epoxy is commonly employed as an electrical insulator because of its low water absorption rate [31].

In the design of the proposed antenna, several techniques have been applied such as partial ground plane (PGP), slotted patch, and defective ground structure (DGS). The narrow band characteristics of the microstrip patch antenna are converted into wide band characteristics using partial ground plane methodology [32]. PGP reduces the energy stored in the substrate and back lobe radiation [33]. Imperfections or defects or slots on the ground plane are referred to as defective ground structure (DGS) in microwave planar circuits [34]. It is used to boost the bandwidth and gain of microstrip antennas, as well as to diminish cross-polarization, dimension, mutual coupling between nearby components and higher mode harmonics [35]. DGS can be a variety of shapes such as concentric ring circles, spirals, dumbbells, elliptical, U and V slots [36]. A patch having slots in the forms of a U, H, T, E, or other shape is known as a slotted patch. The gain, bandwidth, and efficiency of an antenna are increased; while the return loss, VSWR, and antenna size are decreased using this technique. The edge of the microstrip patch is directly connected to a conducting strip in this form of the feed mechanism, as shown in Figure 1. The benefit of this type of feeding configuration is that the feed can be engraved on the same substrate to yield a planar structure. The patch is wider than the conducting strip. This method is popular because it is reasonably easy to design, assess, and produce [37].

2.1. Antenna Structure

The proposed rectangular patch antenna uses a microstrip feedline technique which is more consistent and less complicated than coaxial feedline, aperture coupled feedline, and proximity couple feedline approaches. It is powered by a direct connected microstrip feedline with a

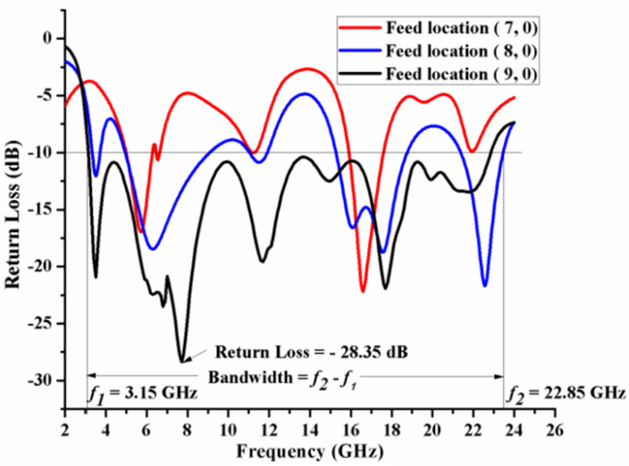

Figure 3. Return loss vs. frequency for (7, 0), (8, 0), (9, 0) feed point position.

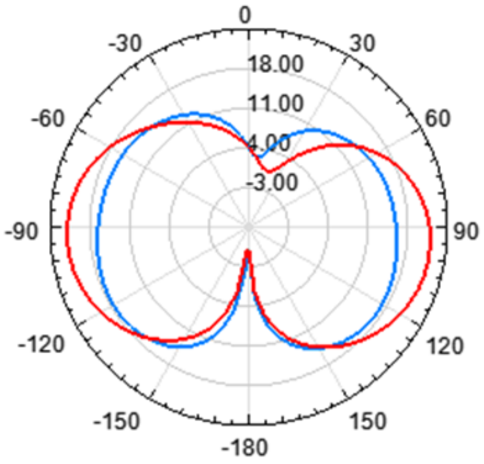

Figure 4. 2D Far-field radiation pattern of the proposed antenna at feed point (9, 0).

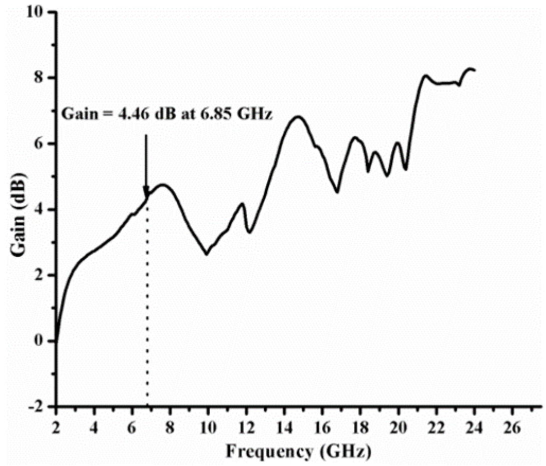

Figure 5. Gain (dB) of the proposed antenna at feed point (9, 0).

characteristic impedance of 50 ohms shown in Figure 1. The size of the feedline is 2 by 15 mm. FR4-epoxy substrate with dimensions of 30 by 20 mm is used to design the antenna. It has a thickness of 0.8 mm, a relative permittivity of 4.4, and a tangent loss of 0.02. Both the patch and the ground are made of copper material. The patch is 14 mm × 18 mm in size. The ground plane is partially employed to increase the impedance bandwidth and to reduce the return loss of the antenna. The size of the PGP is 14 mm in length and 20 mm in width. A rectangular slot referred to as a DGS is inserted into the antenna's partial ground plane, as well as 2 different slots (triangular and rectangular) are implanted into the radiating patch, as illustrated in Figure 2. These modifications are made to increase the impedance bandwidth of the antenna. The evaluation and optimization of this antenna are performed using High-Frequency Structure Simulator (HFSS) software (v.15). Table 1 shows the different design parameters of the proposed antenna.

2.2. Feed Point Position

Microstrip line feeding position is chosen because it offers the best impedance match between the antenna and the feedline. The impedance matching is required for the maximum power transfer. The feed point needs to be placed at that position on the patch where the input impedance is 50 ohms for the operating frequency. It was done by moving the feed point locations using a trial and error basis. The optimal feed point location was selected by comparing the minimal negative return loss (S_{11}) among other feed point positions. The best feed point can be found along the length of the patch where the S_{11} is minimal [38]. In order to determine the optimal feed point in this design, Z was set to zero and only Y was changed.

3. RESULTS AND DISCUSSIONS

A rectangular patch microstrip antenna using a microstrip feeding line approach has been designed and simulated using finite element method based HFSS v.15 software. The substrate thickness is in the X-direction, and the patch antenna is intended to be positioned in the origin's Y-Z plane. A microstrip feedline is considered in the feeding scheme which drastically impacts on the return loss

Table 2. Effect of feed width changes in the return loss and impedance bandwidth

Feed width, W_f (mm)	Return loss (S_{11}) (dB)	Impedance Bandwidth (GHz)
1.0	-27.76	10.0 (3.67–13.67)
1.5	-27.53	10.5 (3.30–13.80)
2.0	-28.35	19.7 (3.15–22.85)
2.5	-25.83	0.84 (3.09–3.93)
3.0	-16.02	7.52 (4.59–12.11)

Table 3. Implication of feed position on operating frequency, return loss, and impedance bandwidth.

Feed position (Y, Z) (mm)	Operating Frequency (GHz)	Minimum Return loss (S_{11}) (dB)	Impedance Bandwidth (GHz)
(7.00, 0)	5.70	-16.98	1.30
(7.25, 0)	3.20	-25.17	1.00
(7.50, 0)	6.60	-15.24	2.10
(7.75, 0)	5.60	-13.69	1.45
(8.00, 0)	6.30	-18.43	4.20
(8.25, 0)	3.40	-24.80	1.50
(8.50, 0)	7.40	-22.83	9.60
(9.00, 0)	**7.70**	**-28.35**	**19.7**
(9.25, 0)	7.70	-23.60	10.9
(9.50, 0)	6.30	-22.80	9.35
(9.75, 0)	6.35	-21.09	8.30
(10.00, 0)	6.55	-18.23	5.10
(10.25, 0)	6.40	-17.12	3.70
(10.50, 0)	6.55	-18.05	3.05
(10.75, 0)	6.20	-15.38	1.60

and bandwidth of the antenna. We have investigated the effect of the feedline's width on the proposed antenna. The width of the feedline varies from 1 to 3 mm to determine the appropriate width of the proposed antenna. Table 2 summarizes the outcomes of the simulation. Variation is observed in the antenna properties by changing the width of the feedline. Table 2 shows that the minimum return loss and the maximum bandwidth are achieved with 2 mm width of feedline. This is the justification for choosing 2 mm width for the proposed antenna and the rest of the analysis has been carried out by this width.

The investigation and simulation processes have been carried out for each of the Y-Z plane feeding location points. The feed point position has been altered along the patch width from the left to the right edge to achieve the best location. The simulated results are shown in Table 3. The ideal operating frequency can be chosen to get the lowest return loss. The difference between the power that is fed into the system and the power that is reflected is known as the return loss, and it is expressed in decibels (dB).

The least S_{11} for the axis (9, 0) is found to be -28.35 dB. The axis (9, 0) is the center of the patch; thus, it can be said that the impedance is perfectly matched at the center of the patch. The values below and above (9, 0) show the worst performance in the return loss and bandwidth of the antenna.

We have carried out the study at 15 different feeding points. Three observations from among 15 feeding point locations are compared in the graph shown in Figure 3. According to our analysis, the selected feed point location has the minimum return loss (-28.35 dB). It is calculated using a S_{11} graph. The bandwidth of an antenna is defined as the frequency range over which S_{11} is less than -10 dB (-10 dB is an acceptable number that represents a VSWR of 2). The suggested antenna has a bandwidth of 19.7 GHz (calculated using -10 dB return loss) ranging from 3.15 to 22.85 GHz with a working frequency of 7.7 GHz at the feed point position (9, 0). This operating frequency is slightly greater than the designed frequency, which is 6.85 GHz.

The radiation pattern, also known as the far-field pattern, describes how the intensity of

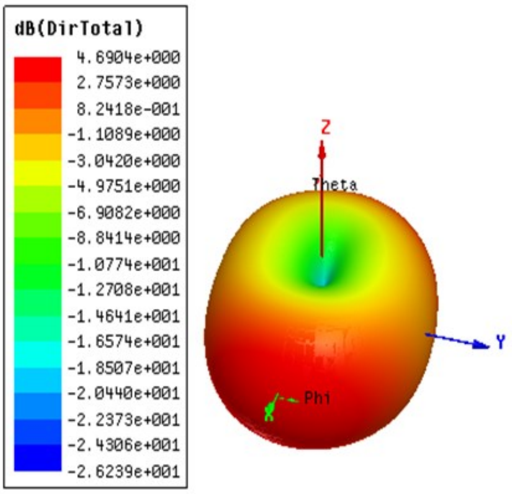

Figure 6. 3D directivity (dB) of the proposed antenna at feed point (9, 0).

Table 4. Comparisons of the current work with recently published work.

Patch Size (mm^2)	Impedance Bandwidth (GHz)	Gain (dB)	Ref.
21.80 × 30.80	0.01 (10.00 MHz)	3.73	[17]
36.10 × 49.40	-	5.35	[19]
38.00 × 30.00	1.00	-	[20]
28.00 × 36.00	0.03 (30.00 MHz)	-	[21]
14.00 × 18.00	19.70 (3.15–22.85)	4.46	This work

electromagnetic waves radiating from an antenna or from other sources. The radiation pattern varies depending on their direction. In the current work, it has been utilized to illustrate how the power radiation is distributed around the antenna as a function of direction as indicated by the phi angle at 6.85 GHz. The most effective method for showing radiation pattern is a three-dimensional graph. The surface of the patch antenna determines radiation magnitude. It can also be represented using polar or angular coordinates. Figure 4 depicts the 2D far-field radiation pattern of the proposed antenna at the feed point position (9, 0) at phi = 0° and 90° degrees. This pattern closely mimics a dipole antenna and has a maximum radiated power of 22.19 dB at phi = 0° and 90° at 6.85 GHz, which represents a substantial benefit in ultra-wideband communication technology.

The gain of an antenna measures the amount of energy transmitted from an isotropic source in the direction of maximum radiation. The gain of the proposed antenna at feed point (9, 0) is shown in Figure 5. The suggested antenna attains a gain of 4.46 dB at 6.85 GHz.

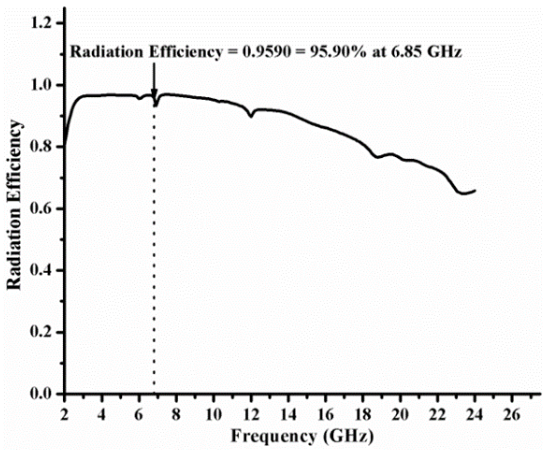

Figure 7. Radiation efficiency of the proposed antenna at feed point (9, 0).

Directivity is a simple factor to determine the range of energy transmission in a specific direction. It is one of the factors that affect the gain of the antennas. Figure 6 shows the directivity of the proposed antenna at feed point position (9, 0). The antenna provides a high directivity of 4.6904 dB at feed point location (9, 0).

The output power to input power ratio is used to determine the efficiency of any system, but the radiated power to input power ratio is used to measure the antenna efficiency. The antenna functions similarly to all other components of a microwave circuit. Dielectric losses or mismatches are two factors that can lead to power loss. The radiation efficiency of the planned antenna at feed point (9, 0) is shown in Figure 7. The radiation efficiency is found to be 95.90% at the optimal feed point with operating frequency of 6.85 GHz.

Table 4 compares the performance assessments of the proposed antenna with a few previously developed antennas. It is clear from this table that a significant gain and a narrow bandwidth were achieved using a large antenna size [17]-[21]. However, the suggested antenna is smaller than the observed antennas [17]-[21] and has a wider bandwidth of 19.7 GHz (3.15 to 22.85 GHz), which boosts the higher data rates.

4. CONCLUSIONS

The effectiveness of a rectangular patch antenna can be varied by altering the feed point locations. The best outcome of the 15 feeding locations of the proposed antenna on the FR4_epoxy substrate has been investigated. The findings show that the feed point (9, 0) yields superior results. It implies that there is better impedance matching between the feedline and patch at this point. The proposed antenna has a return loss of -28.35 dB, a bandwidth of 19.7 GHz from 3.15 to 22.85 GHz, a gain of 4.46 dB, a directivity of 4.6904 dB and a radiation efficiency of 95.90% at the feed point position (9, 0). The developed antenna can be used for X-band, C-band, Ku-band, S-band, and STM band applications in addition to other wireless applications including WiMAX, Wi-Fi, WLAN, radio astronomy, communications and sensors, position location and tracking, satellite communication, and radar communication.

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Conflicts of Interest

The author(s) declare no conflict of interest.

REFERENCES

[1] S. M. Wentworth. (2005). "Fundamentals of Electromagnetics with Engineering Applications". John Wiley & Sons Incorporated.

[2] K. Guney and N. Sarikaya. (2007). "Adaptive neuro-fuzzy inference system for computing the resonant frequency of electrically thin and thick rectangular microstrip antennas". *International Journal of Electronics.* **94** (9): 833–844. 10.1080/00207210701526317.

[3] B. Abdennaceur and A. Badri. (2014). "Effect of Change in Feedpoint on the Antenna Performance in Edge, Probe and Inset-Feed Microstrip Patch Antenna". *International Journal of Emerging Trends in Engineering and Development.* **1** (4): 80–93.

[4] A. Vasekar and M. Mathpatti. (2018). "Effect of Feed Point Position on Metamaterial Based Patch Antenna". *International Journal of Advanced Computational Engineering and Networking.* **6** (7): 33–37.

[5] R. S. A. Kumar and J. Kaur. (2013). "Performance Analysis of Different Feeding Techniques". *International Journal of Emerging Technology and Advanced.* **3** (3).

[6] K. S. Naik, S. Aruna, K. Y. K. G. R. Srinivasu, and D. S. Kiran. (2017). "Comparative Analysis of Rectangular Microstrip Patch Array Antenna with Different Feeding Techniques". *the International Conference on Recent Advances and Future Trends in Information Technology*.

[7] K. S. Fong, H. F. Pues, and M. J. Withers. (1985). "Wideband multilayer coaxial-fed microstrip antenna element". *Electronics Letters.* **21** (11): 497-499. 10.1049/el:19850352.

[8] Y. Gupta. (2014). "Stacked Microstrip Patch Antenna with Defected Ground Structures for WLAN and Wimax Applications". *the 4th World Congress on Information and Communication Technologies (WICT 2014)*.

[9] L. I. Basilio, M. A. Khayat, J. T. Williams, and S. A. Long. (2001). "The dependence of

the input impedance on feed position of probe and microstrip line-fed patch antennas". *IEEE Transactions on Antennas and Propagation.* **49** (1): 45–47. 10.1109/8.910528.

[10] M. Civerolo and D. Arakaki. (2011). "Aperture coupled patch antenna design methods". *IEEE Antennas and Propagation Society.* 10.1109/APS.2011.5996415.

[11] G. Krishnaveni and B. Manimegalai. (2021). "Efficient and optimized design of a stacked patch microstrip antenna for next generation network applications". *Journal of Ambient Intelligence and Humanized Computing.* **12** (3): 4093–4099.

[12] D. Chatterjee and A. K. Kundu. (2017). "Performance analysis and comparative study of microstrip patch antenna using aperture coupled and proximity coupled feeding methodology". *the International Conference on Computer, Communication, and Signal Processing.*

[13] A. Mandal, A. Ghosal, A. Majumdar, A. Ghosh, A. Das, and S. K. Das. (2012). "Analysis of feeding techniques of rectangular microstrip antenna". *the IEEE International Conference on Signal Processing, Communications and Computing.*

[14] M. Biswas and M. Sen. (2019). "Fast and accurate model for a coax-fed rectangular patch antenna with varying aspect ratio, feed location and substrate electrical parameters". *Journal of Electromagnetic Waves and Applications.* **33** (4): 428–453. 10.1080/09205071.2018.1554512.

[15] P. Paul, J. S. Roy, and S. K. Chowdhray. (1996). "Effect of feed location on rectangular microstrip antenna at TM11 mode". *Defence Science Journal.* **46** (3): 127–134. 10.14429/dsj.46.4059.

[16] S. Stefanovski and B. Kolundzija. (2014). "The impedance variation with feed position of a microstrip line-fed patch antenna". *Serbian Journal of Electrical Engineering.* **11** (1): 85–96. 10.2298/SJEE131121008S.

[17] T. Divakar and D. C. Panda. (2014). "Finding Optimal Feed Location of a Microstrip Patch Antenna using HFSS". *International Journal of Innovative Research In Electrical, Electronics, Instrumentation And Control Engineering.* **2** (10): 2143–2145. 10.17148/IJIREEICE.2014.21105.

[18] S. E. Jasim, M. A. Jusoh, M. H. Mazwir, and S. N. S. Mahmud. (2015). "Finding the best feeding point location of patch antenna using HFSS". *ARPN Journal of Engineering and Applied Sciences.* **10** (23): 17444–17449.

[19] M. B. Hossain, M. S. Hossain, M. M. Hossain, and M. D. Haque. (2020). "Optimization of the feeding point location of rectangular microstrip patch antenna". *Advances in Science, Technology and Engineering Systems.* **5** (1): 382–386. 10.25046/aj050149.

[20] A. R. Celik. (2021). "Effects of the Feedline Position on Microstrip Patch Antenna Performance". *Engineering and Technology Journal.* **6** (12): 1084–1087. 10.47191/etj/v6i12.03.

[21] J. M. Mom and A. L. Tersoo. (2013). "Impact of Feed Point Location on the Bandwidth, Frequency and Return Loss of Rectangular Microstrip Patch Antenna". *International Journal of Engineering Research and Technology.* **2** (9): 1612–1616. 10.5120/ijais13-451054.

[22] J. M. Môm, A. A. Roy, and D. T. Kureve. (2013). "Investigation of the Effect of Feed Variation on the Performance of a Circular Patch Microstrip Antenna". *International Journal of Applied Information Systems.* **6** (5): 1–4.

[23] M. Alibakhshikenari, B. S. Virdee, P. Shukla, Y. Wang, L. Azpilicueta, M. Naser-Moghadasi, and E. Limiti. (2021). "Impedance bandwidth improvement of a planar antenna based on metamaterial-inspired T-matching network". *IEEE Access.* **9** 67916–67927.

[24] M. Alibakhshi-Kenari, M. Naser-Moghadasi, R. A. Sadeghzadeh, B. S. Virdee, and E. Limiti. (2017). "New CRLH-based planar slotted antennas with helical inductors for wireless communication systems, RF-circuits and microwave devices at UHF–SHF bands". *Wireless Personal*

Communications. **92** (3): 1029–1038. 10.1007/s11277-016-3590-4.

[25] M. Alibakhshi-Kenari, M. Naser-Moghadasi, R. A. Sadeghzadeh, B. S. Virdee, and E. Limiti. (2016). "Miniature CRLH-based ultra -wideband antenna with gain enhancement for wireless communication applications". *ICT Express*. **2** (2): 75–79. 10.1016/j.icte.2016.04.001.

[26] M. Alibakhshikenari, B. S. Virdee, V. Vadalà, M. Dalarsson, M. E. Cos Gómez, A. G. Alharbi, S. N. Burokur, S. Aïssa, I. Dayoub, F. Falcone, and E. Limiti. (2022). "Broadband 3-D Shared Aperture High Isolation Nine-Element Antenna Array for On-Demand Millimeter-Wave 5G Applications". *Optik*. **267** : 169708. 10.1016/j.ijleo.2022.169708.

[27] M. Alibakhshikenari, B. S. Virdee, H. Benetatos, E. M. Ali, M. Soruri, M. Dalarsson, M. Naser-Moghadasi, C. H. See, A. Pietrenko-Dabrowska, S. Koziel, S. Szczepanski, and E. Limiti. (2022). "An innovative antenna array with high inter element isolation for sub-6 GHz 5G MIMO communication systems". *Scientific Reports*. **12** (1): 7907. 10.1038/s41598-022-12119-2.

[28] M. Alibakhshikenari, B. S. Virdee, A. A. Althuwayb, L. Azpilicueta, N. O. Parchin, C. H. See, R. A. Abd-Alhameed, F. Falcone, I. Huynen, T. A. Denidni, and E. Limiti. (2021). "Bandwidth and gain enhancement of composite right left handed metamaterial transmission line planar antenna employing a non foster impedance matching circuit board". *Scientific Reports*. **11** (1): 7472. 10.1038/s41598-021-86973-x.

[29] M. Alibakhshi-Kenari, M. Naser-Moghadasi, R. A. Sadeghzadeh, B. S. Virdee, and E. Limiti. (2016). "Bandwidth extension of planar antennas using embedded slits for reliable multiband RF communications". *AEU-International Journal of Electronics and Communications*. **70** (7): 910–919. 10.1016/j.aeue.2016.04.003.

[30] M. Alibakhshi-Kenari, M. Naser-Moghadasi, R. A. Sadeghzadeh, B. S. Virdee, and E. Limiti. (2016). "A New Planar Broadband Antenna Based on Meandered Line Loops for Portable Wireless Communication Devices". *Radio Science*. **51** (7): 1109–1117. 10.1002/2016RS005973.

[31] M. Márton. (2017). "Design and Analysis of Microstrip Antenna for 2.46GHz in Program Suite FEKO". 31–34.

[32] M. Parihar. (2017). "Design of Bandwidth Enhanced Rectangular Microstrip Patch Antenna with Rectangular Slot using Partial Ground Plane Technique for UWB Applications". *International Journal of Advance Engineering and Research Development*. **4** (11): 79–82. 10.21090/IJAERD.99866.

[33] A. Viswanathan and R. Desai. (2014). "Applying Partial-Ground Technique to Enhance Bandwidth of a UWB Circular Microstrip Patch Antenna". *International Journal of Scientific & Engineering Research*. **5** (10): 780–784.

[34] M. K. Khandelwal, B. K. Kanaujia, and S. Kumar. (2017). "Defected ground structure: Fundamentals, analysis, and applications in modern wireless trends". *International Journal of Antennas and Propagation*. 10.1155/2017/2018527.

[35] B. G. Breed. (2008). In: " High frequency electronics". 1–3.

[36] A. Abderrahim. (2018). "Bandwidth Improvement of Microstrip Patch Antenna using DGS Technique Approved by supervising committee". *Department of Electronics and Telecommunications, Université Kasdi Merbah Ouargla*.

[37] S. Rana, A. Thakur, H. S. Saini, R. Kumar, and N. Kumar. (2016). "A wideband planar inverted F antenna for wireless communication devices". *the International Conference on Advances in Computing, Communication and Automation*.

[38] C. A. Balanis. (2016). "Theory, Analysis and Design". John Wily & Sons Inc, New York.