ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

Radiation Pattern Reconfigurable Antenna with Direction Resolution

Iddrisu Awal

College of Electronic and Information Engineering, Shandong University of Science and Technology, Qingdao 266590, China.

1198315756@qq.com

Abstract

Reconfigurable antennas, with the ability to radiate more than one pattern at different frequencies and polarizations, are necessary in modern telecommunication systems. The radiation pattern reconfigurable antenna has led to many novel designs of reconfigurable antennas using different techniques and have different phase covered. The objective of this paper is to overcome the limitation of beam angle polarization. A considerable amount of literature has been published on the radiation pattern reconfigurable antenna. The aim of this research is to design and develop a radiation pattern reconfigurable antenna with direction resolution ensuring full coverage extension on the azimuthal plane. In this work, the radiation pattern is configured by the insertion of metal rods around the patch antenna. The radiation pattern does change accordingly. An antenna that has a radiation pattern with full coverage on azimuthal plane is beneficial for an application that would requires signal transmitted or received in all directions.

Keywords

Patch antenna, Antenna reconfiguration, Direction resolution.

1. Introduction

Reconfigurable antenna is fast becoming a key instrument in communication technology nowadays. Modern wireless communication devices require an antenna with a capability to work in more than one operational mode in a single structure. Thus, reconfigurable antennas are designed to resolve the problem as well as offer new capabilities to adapt in future wireless applications. In this chapter, the history of reconfigurable antenna is discussed in detail. Multiple techniques in attaining reconfigurable characteristic are discussed and studied closely. The example for each technique is also presented in this section. The analysis of antenna performance can be conducted through various ways. The analysis method for antenna performance is discussed briefly in Section 3, which contributes to the introduction of Ansys HFSS. Ansys HFSS is applied vastly in the development of the antenna design in this study. The advantages of using the software are all presented in Section 3.3

Pattern reconfigurable antenna is crucial in modern communication system due to its adaptable quality to the system requirement. This smart antenna can unravel the hidden nodes due to lack of coverage problem by directing the signal toward the right directions. It has previously been observed that most pattern reconfigurable antenna design are capable of having multiple radiation pattern in a single design and does not support full beam coverage in one single plane. To cover multiple frequency bands by a single antenna element, various design approaches such as a multi-frequency antenna covering each individual band [1]. The mechanism of operation for the proposed antenna design of radiation pattern reconfigurable antenna is explained in Section 3.2. Radiation pattern

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

reconfigurable characteristic of the circular patch antenna is achieved by adding a parasitic element in the design. The radiation pattern of the antenna can be modulated to a fine direction resolution of 10° when a single parasitic element is activated. The critical parameters of the proposed antenna are presented in Section 4.1. The return loss and radiation pattern of the proposed antenna are analysed and studied thoroughly. The parametric study on the proposed method is studied in Section 4.2 and Section 4.3.

1.1 Background

The demand in modern communication technology has been expanding rapidly, thus a smart antenna with the ability to change its parameter according to the system need is crucial and beneficial. Advanced wireless system necessitates an antenna with the ability to transmit and receive signal in all horizontal direction equally, and at the same time can be a directional antenna when preferred.

Primarily, the first objective of this research is to design an antenna with full coverage extension. An antenna with Omni directional radiation pattern is beneficial for an application that would requires signal transmitted or received in all directions, i.e. mobile base station. Therefore, a conventional patch antenna is modified to give an Omni directional radiation pattern with insertion of shorting pin.

After that, the radiation pattern is configured using the insertion of metal rods around the patch antenna. An antenna with a deviation in radiation pattern in all manner of angles in single plane is very beneficial for modern communication system. The addition of metal rods resulted in the antenna becoming a directional antenna according to which metal rod activated. The radiation pattern does change accordingly but with the cost of large size of the antenna build-up. The radiation pattern reconfigurable antenna in the earlier part of this research has an extensive dimension. A compact design is more tempting for an application in modern communication technology. Patch antenna has been acknowledged to have low profile design and easy to fabricate, thus it is opted for this work.

2. Antenna Design

2.1 Principle of Operation

The The pattern reconfigurable manners of the proposed antenna design are constructed based on the operating principle of Yagi-Uda antenna, which was developed by H. Yagi and S. Uda at Tohoku Imperial University in Sendai, Japan [2] and [3]. The basic construction of Yagi –Uda antenna is comprised of a reflector, a driven element and a director. These will cause phase distribution to occur, which leads to Yagi-Uda antenna to function as an end-fire beam. It has conclusively been shown that the total phase of currents in the radiators is determined by the length and spacing between the radiators. By adopting this concept, a metal element is introduced into the shorted circular patch antenna. An element which is physically longer than resonant length will become reflector. The impedance of reflector is inductive, and the induced currents lag in phase from the current induced by the driven element [4].

2.2 Combination of Reconfiguration Characteristics

Along with the rapid development in communication technology, more antenna design has been developed which incorporated two or three reconfigurable characteristics to fulfill the demand. In a recent research paper by [5], the frequency and radiation pattern of the circular array antenna can be altered without adapting a switching mechanism into the design. The antenna features a power divider and eight horn antenna elements with respective band stop filters uniformly distributed around the circular ground plane. A directional radiation pattern can be generated at a particular frequency by controlling the band notch filters and the frequency is controlled by voltage applied to the varactor inside the filters as shown in the **Figure 1**. When none of the filters are activated, an Omni directional radiation pattern on azimuth plane is produced. The antenna design successfully operating between 0.8 to 3 GHz with six different modes including Omni directional radiation pattern. However, in this paper, the element is disconnected to represent when the filter is not activated.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

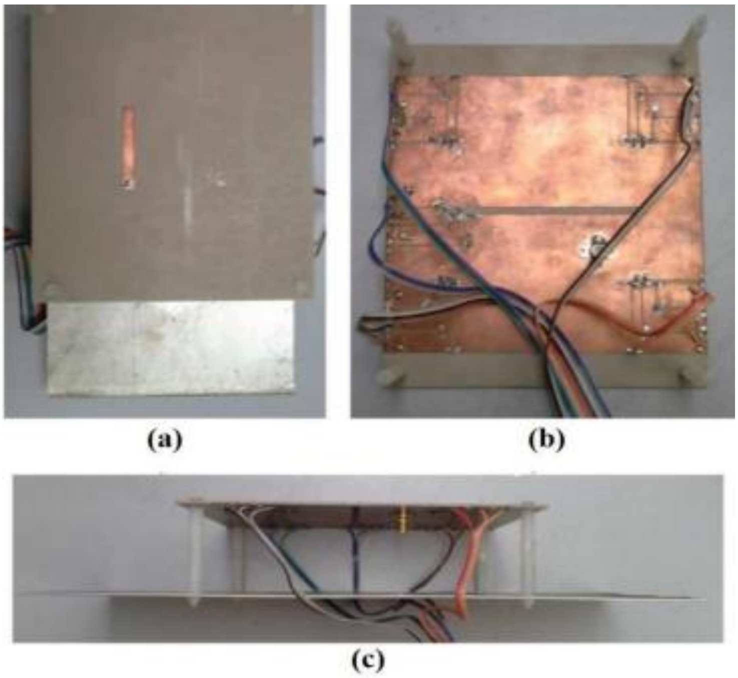


Figure 1. Radiation pattern on azimuth plane when metal rod is inserted.

antenna design with frequency reconfigurability and radiation pattern characteristics has been proposed in [6], [7], [8]. The antenna in [6] operates in three frequency bands, depending on the length of the slot with the manipulation of two switches. The introduction of four slits in the ground plane of the slot antenna held many functions in the antenna design. Not only it serves as biasing circuit, it is also exploited to attain reconfigurability in radiation pattern of the antenna. Each slit is installed with three switches to control the length as well as terminating it in each different configuration. In this design, the radiation pattern emitted is independent of the frequency band. By switching the upper and bottom part of the slits, the beam angle can be shifted into +15˚, 0˚ and -15˚. Even though the antenna has a high efficiency in all frequency bands, the shifted angle introduced by the slits is not major and restricted on one direction only despite of the four slits fitted on the design.

2.3 Design

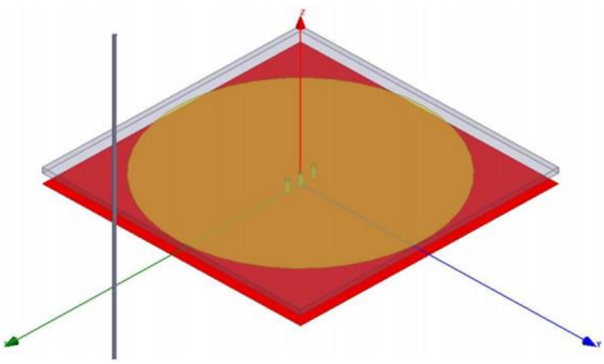


Figure 2. The construction of reconfigurable circular patch antenna using metal rod in HFSS

When the electric field from the metal rod met the electric field from the radiating patch, it will result in constructive wave collision in the opposite direction to the position of metal rod. Thus, it results in power reflected away from the parasitic element and the maximum power is in the opposite direction to the position of metal rod. **Figure 2** and **Figure 3** show the configuration of proposed antenna design and how the radiation pattern change respectively. The metal rod length is 150 mm, which is $\lambda/2$ and placed 58mm from the centre of radiating patch. Other components of the antenna are also

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

verified to find the most desirable gain. Each metal cylinder has a radius of 0.5 mm to give maximum gain.

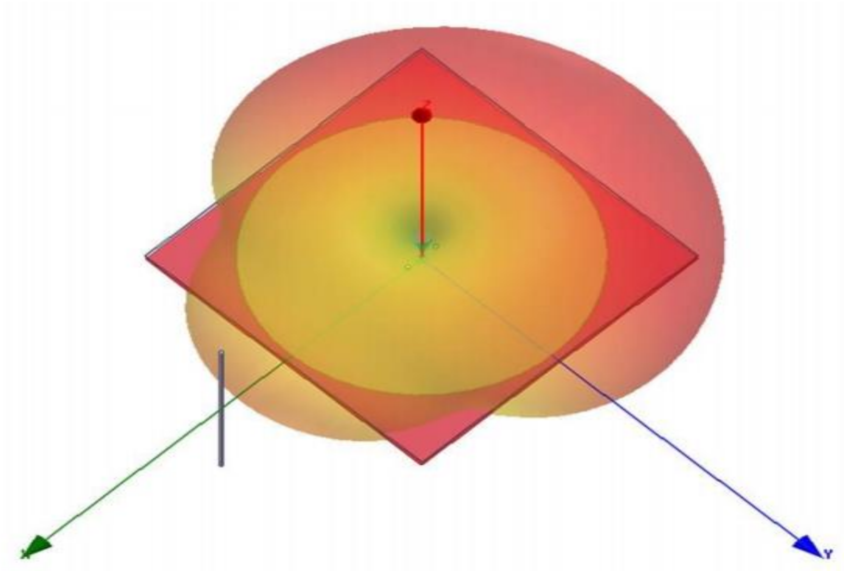


Figure 3. The Radiation pattern change in 3D plot when metal rod is inserted.

The reconfigurable characteristic of the antenna is controlled by having a different overall length of metal rod at one time. The length of metal rod is controlled using PIN diode as a switch. The PIN diode is located in the middle of the metal element. PIN diode serves to open or close a current path connecting the metal cylinder, which gives the total length of metal rod. PIN diodes are less susceptible to electrostatic discharge damage compared to other switches[20]. Forward biasing a PIN diode creates a very low resistance at high frequencies, while reverse biasing results in an open circuit.

2.4 Radiation Pattern

Radiation pattern of an antenna can be defined as a mathematical function or a graphical representation of the radiation properties of the antennas as a function of space coordinates [9]. In other words, radiation pattern can be defined as the variation of the power radiated by an antenna as a function of the direction away from the antenna. the radiating elements (top patches and bottom patches) are etched on different substrate layers, i.e., on the top of substrate layer 1 and substrate layer 2, respectively, with a unique structure and shape [10]. Typically, radiation pattern is measured in far-field region and represented in two- or three- dimensional space. When plotting the radiation pattern, the units or magnitude of the pattern are mostly measured in antenna gain [11]. An antenna which transmits or receives signal equally on a single plane has an Omni directional radiation pattern as shown in **Figure 4** and **Figure 5**. The radiation pattern analysis is more significant for directional antenna as it express the directive properties of the antenna. In general, an Omni directional antenna has a comparatively low gain compared to directional antennas as the power radiates in all directions. Pattern reconfigurable antenna can provide diversity in the radiation pattern which leads to an increase of the number of users in wireless communication system without increasing the number of array elements [12]. Monopole antenna is an example of antenna with Omni directional radiation pattern, and horn antenna is a good example of directional antenna.

Furthermore, the overall performance of modern wireless communication system is greatly improved as the antennas can be used to avoid inter-user interference, improve security as well as saving energy by directing the signal to the right direction [13]. There is a growing body of literature that recognizes the importance of radiation pattern reconfigurable antenna, such as in [14] and [15]. Generally, the radiation pattern can be changed in two different ways subjected to system requirements: 1) shifting the main beam while maintain the beam shape or 2) shifting the main beam while changing the beam shape. The microstrip Yagi-Uda antenna design in [16] is a good example of the first case. The peak

ISSN: 2414-1895
DOI: 10.6919/ICJE.202009_6(9).0030

beam direction of the planar Yagi-Uda antenna switched in opposite direction (±180˚) while maintaining the beam shape and matching bandwidths at a fixed operating frequency. The maximum gain of the antenna is not significant; however more focus is given to the front-to-back ratio. For the latter case, a simple configuration of pattern reconfiguration antenna with three switches that control the radiation pattern from Omni directional to directional pattern is presented in [17], [18].

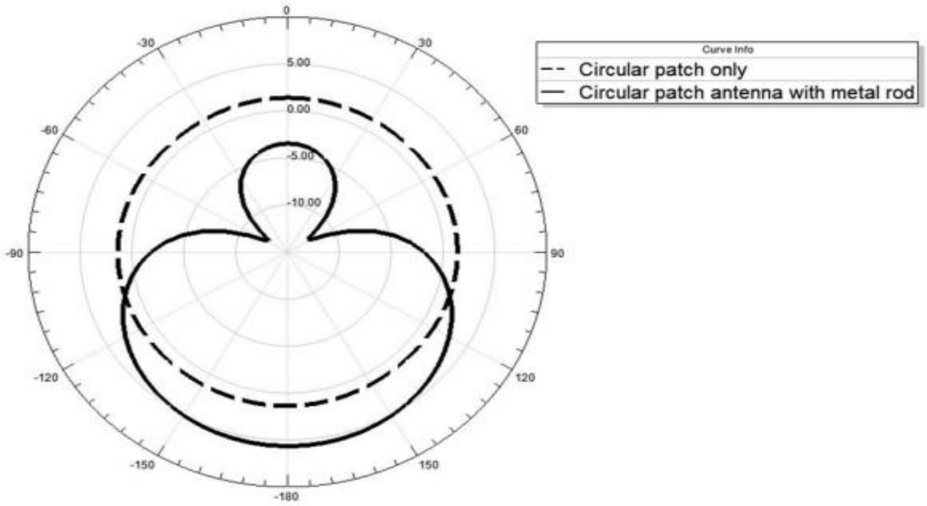


Figure 4. Radiation pattern on azimuth plane when metal rod is inserted.

The different position of the activated metal cylinder around the circular patch antenna will determine the shape of the radiation pattern accordingly. When the PIN diode is triggered, the metal rod will act as a reflector where the gain of the radiation pattern is highest in the opposite direction compared to other direction. In this study, the application of PIN diode as a switch is not studied as the primary focus is on proving the main concept.

The activated metal rod will have a full length, while non-activated metal rod will be shorter than a full-length metal rod. The full wave analysis of the reconfigurable antenna is conducted in HFSS. For the purpose of simulation, the metal cylinder is divided into two and separated by an empty cylinder to signify when the switch is off. When the switch is activated, the two metal cylinders are united which gives a total length of λ/2.

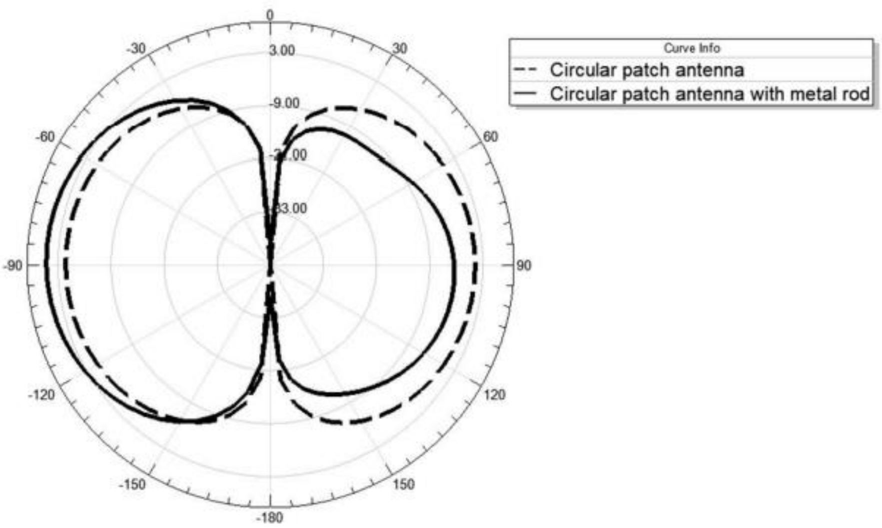


Figure 5. Radiation pattern on azimuth plane when metal rod is inserted.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

3. Analysis

There are many method of analysis that has been developed by researchers up to this present day. These methods can be divided into two: 1) Time-domain analysis and 2) Frequency-domain analysis. Based on these two methods, many commercial software have been developed to help in analysis of radio frequency design. In this part of the chapter, the foundation principles for each technique are explained briefly and radiation pattern simulated in section 3.3.

3.1 Analysis Methods

3.1.1 Finite Different Time Domain (FDTD)

The Finite Different Time Domain (FDTD) is a widely used method to solve several electromagnetic problems. The literature on FDTD is extensive and has been used in various microwave analysis such as antenna designs, propagation, filter designs and many other microwave analysis. However, the shortcoming of FDTD comes as it is not suitable for electrically huge system but good for system involving pulses. This method did not gain considerable attention despite its usefulness to handle electromagnetic problems until the computing costs become affordable. The FDTD iteratively calculates the field values in the problem space that is discredited

3.1.2 Finite Element Method (FEM)

The finite element method (FEM) is a mathematical technique used for finding approximate solutions of partial equations as well as of integral equations. The solution is based on reducing the differential equations, and then integrated numerically using Euler’s method which is a standard technique such as the Runge-Kutta. FEM is a method used to solve frequency domain boundary valued electromagnetic problems using a variation form.

There are generally two types of analysis that are used in FEM, which is 2-D and 3-D canonical elements of differing shape. Even though 2-D conserves simplicity and allow itself to be run from a normal computer, the results are less accurate compared to 3-D. The 3-D canonical element gives a more accurate result by working effectively on faster computer. The FEM is often used in frequency domain for computing the frequency distribution in complex, closed regions such as cavities and waveguides.

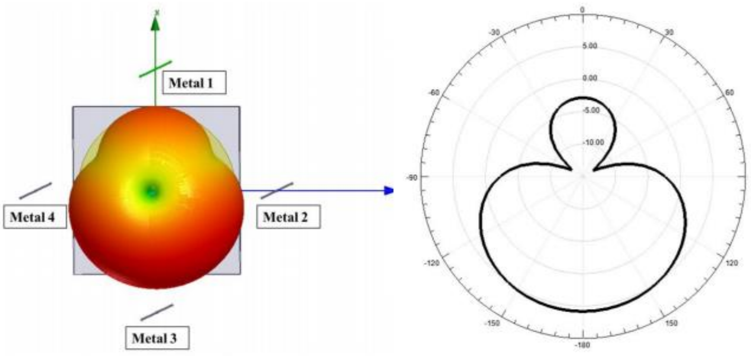
3.2 High Frequency Structural Simulator

All the experiment and simulation to study the electromagnetic field of an antenna is conducted in ANSYS High Frequency Structural Simulator (HFSS). Ansys HFSS is graphic design software with industry standard for executing accurate and rapid designs in high frequency and high speed electronic devices. It takes some time to become proficient at HFSS including designing the antenna structure with precise dimension and element. HFSS plays a great role in analyzing all the important parameters in antenna, such as antenna gain, bandwidth, radiation pattern, and reflection coefficient of an antenna. In this design, only cavity model and full-wave analysis can be conducted appropriately. High Frequency Simulation Software (HFSS) is used to conduct the full wave analysis by solving Maxwell’s Equation.

3.3 Radiation Pattern with Metal Rod Inserted

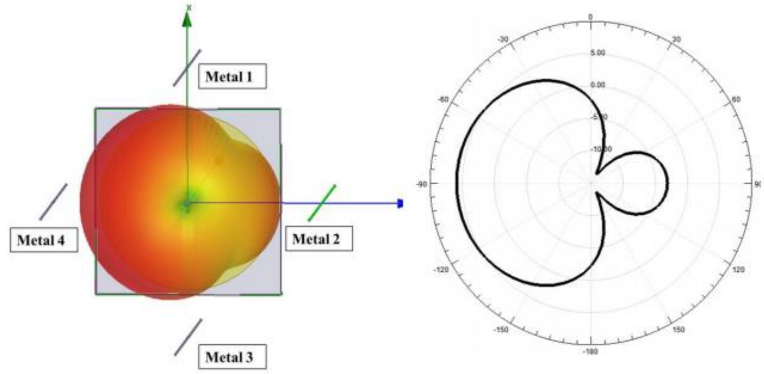
As shown in the previous section, the radiation pattern of the proposed antenna changes with the insertion of a metal rod. When activated, the full-length metal rod operates as a reflector and the Omni directional radiation pattern of the shorted patch antenna will change accordingly. radiation pattern were obtained by an Agilent N5230A network analyzer and a Satimo Starlab near-field measurement system [19]. The reconfigurable characteristics of the proposed antenna are attained by activating different metal rod at one time. The direction of maximum gain changes as different metal rod is activated. In this study, the main goal is to have a reconfigurable antenna covering all beam direction in azimuth plane. Following this objective, metal rods are placed around the shorted circular patch antenna to contend with the whole azimuth plane.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

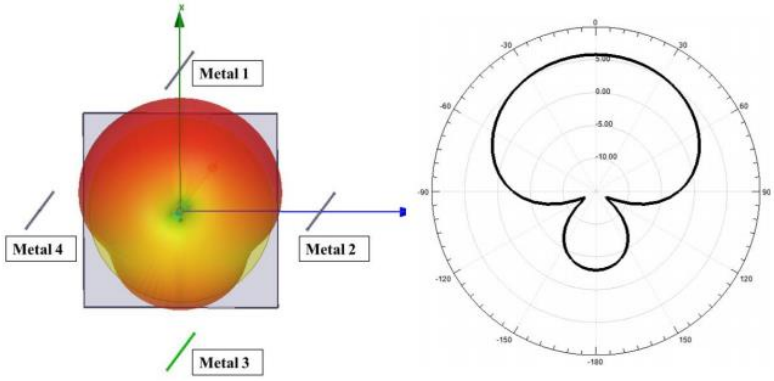


(a)

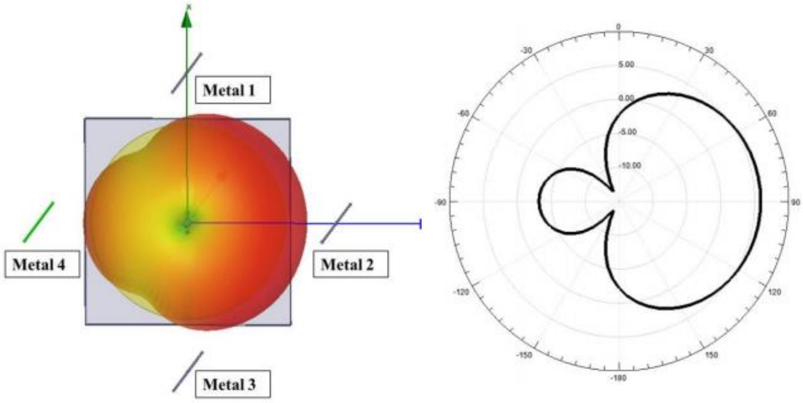
Figure 6. Radiation patterns on azimuth plane when different metal is activated on Metal 1



(b)



(c)



(d)

Figure 7. Radiation patterns on azimuth plane when different metal is activated (b) Metal 2 (c) Metal 3 and (d) Metal 4

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

The initial Omni directional radiation pattern of shorted patch antenna allows more room in the radiation pattern reconfiguration. The distance between the metal rods and the centre of radiating patch is maintained while the position of metal rod is varied. To see the changes in radiation pattern with the activation of different metal rod clearly, four metal rods are placed around the antenna. The metal rod is turn on individually and the changes in radiation pattern are observed. The radiation pattern of the reconfigurable antenna is shown in the **Figure 6** and **Figure 7**. When Metal 1 is activated, the radiation pattern has a maximum gain opposing to the position of Metal 1and so on. Figure 3.5 shows the radiation pattern in 3D and 2D plane for each consecutive metal activated.

Subsequently, the metal rods are placed carefully next to each other. The finest beam resolution with adjacent elements activated is investigated and the changes in the radiation pattern are recorded. The metal rods are placed at 10° angle adjacent to each other**. Figure 8** and **Figure 9** presents the simulated data on fine resolution radiation pattern.

As can be seen from the figure, the radiation patterns of the antenna change accordingly when the metal rod is activated individually. However, based on the simulated data, there are some discrepancies in the radiation pattern when Metal C is activated. This might be due to the mutual coupling occurs when more metal rods are located close to each other

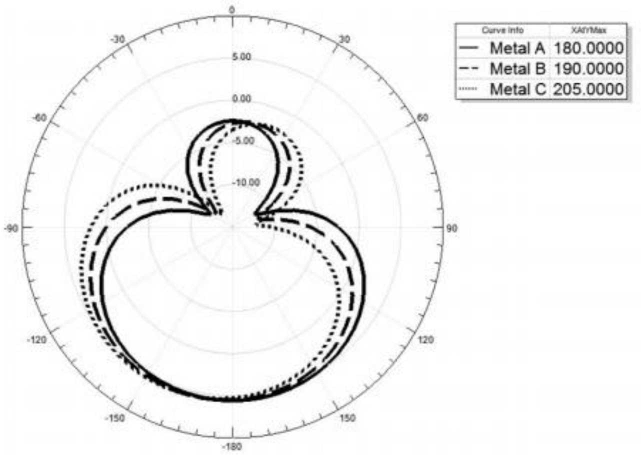


Figure 8. Radiation pattern on azimuth plane when different metal is activated

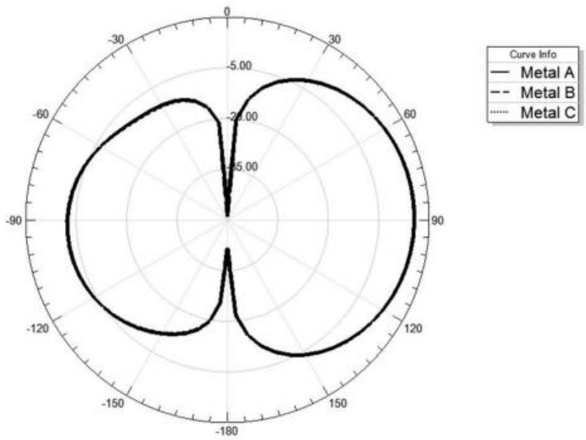


Figure 9. Vertical cut of the radiation pattern at their consecutive maximum direction

4. Results and Discussion

4.1 Return loss

Although more focused is laid on the radiation pattern in this research, return loss and frequency response of the reconfigurable antenna is still crucial in the antenna design. A reconfigurable radiation pattern has a capability of changing the radiation pattern without affecting the frequency response of

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

the antenna. The proposed antenna design is operating at 1 GHz frequency. To illustrate how the antenna functions for different configurations, the surface current distribution was studied [18]. As can be seen from **Figure 10**, the return loss and frequency response of the reconfigurable antenna is maintained at 1 GHz despite the addition of metal rods to the shorted circular patch antenna. However, there is some decrease in the antenna bandwidth when the metal rod is inserted.

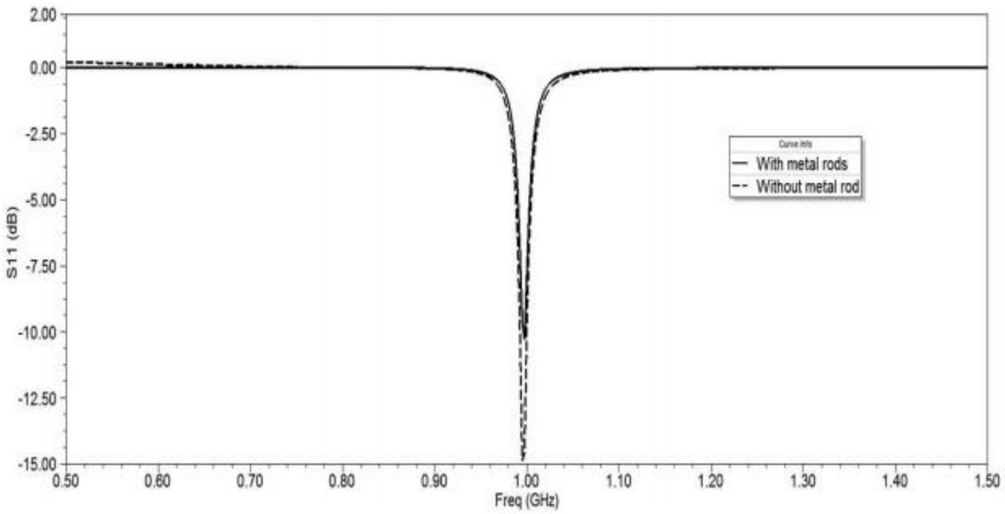


Figure 10. Simulated frequency response of the proposed antenna design with and without the insertion of metal rods.

The parameters that show the most effect are length and the distance between metal rod and centre of patch radiator. Length and position of metal rod have an impact on the maximum gain of radiation pattern. In order to check the changes of the radiation pattern, parametric studies for each parameter have been carried out and obtained from iterative simulation with initial data. Optimization function in HFSS is utilized to give the optimal result.

The total phase of currents in the antenna design is not determined exclusively on length but also by the spacing to the relating elements. It is crucial to have the metal element to be placed appropriately so that it will act as a reflector. Later in 1973, Cheng and Chen has proven that the maximum forward gain is obtained by optimizing the spacing between the parasitic elements before published another paper on optimum element lengths for Yagi-Uda arrays [3]. Taking this approach, the proposed antenna design also paid extra consideration into the spacing of metal element to obtain maximum directivity.

The full length of metal rod when activated is around half free-space wavelength. In a configuration of Yagi-Uda antenna, the length of parasitic structure determines the behavior of the element. A physical length of a reflector is slightly longer than resonant length and a director is typically shorter than resonant length. The proposed antenna design applied the same concept; thus, the length of metal rods is selected at half of free-space wavelength.

The maximum gain of the radiation pattern is observed for different length of metal rod to give a maximum gain. The maximum gain is measured opposing to the position of metal rods, assuming the metal rod behaves as a reflector. The graph of correlational analysis is presented in Figure 3.9 above. Closer inspection of the graph shows that there is a small decline in the maximum gain with the length of metal rod closer to $\lambda/2$. Also, the sudden drop in maximum gain at that particular direction is because the metal rod started to act more as a director and less as a reflector. Even though the maximum gain for the last measurement is reduced, the front-to-back ratio of the measurement is more significant than the earlier case. The front-to-back ratio for each case is also crucial when deciding the length of the metal rod. In **Figure 11**, there is a clear trend of decreasing in the back gain when the length of metal rod closer to λ/2.

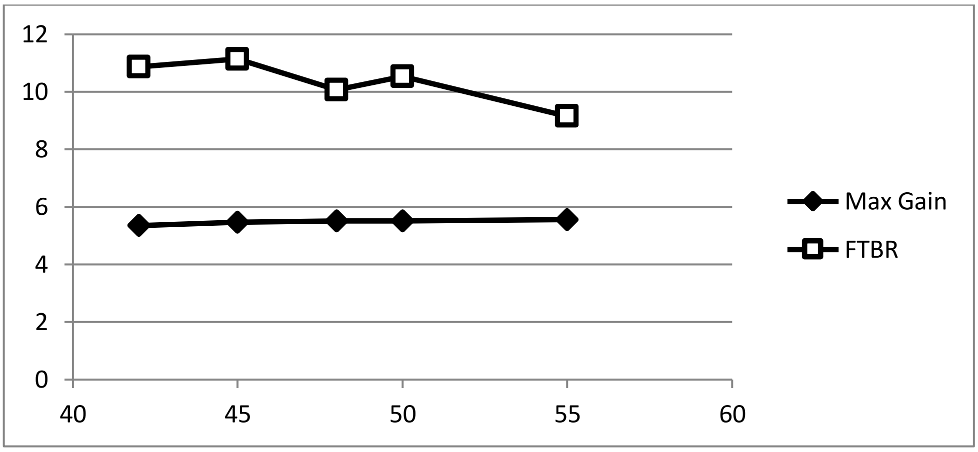


Figure 11. The relationship between length of metal rod and the maximum gain of antenna.

4.2 Effect of changing the distance

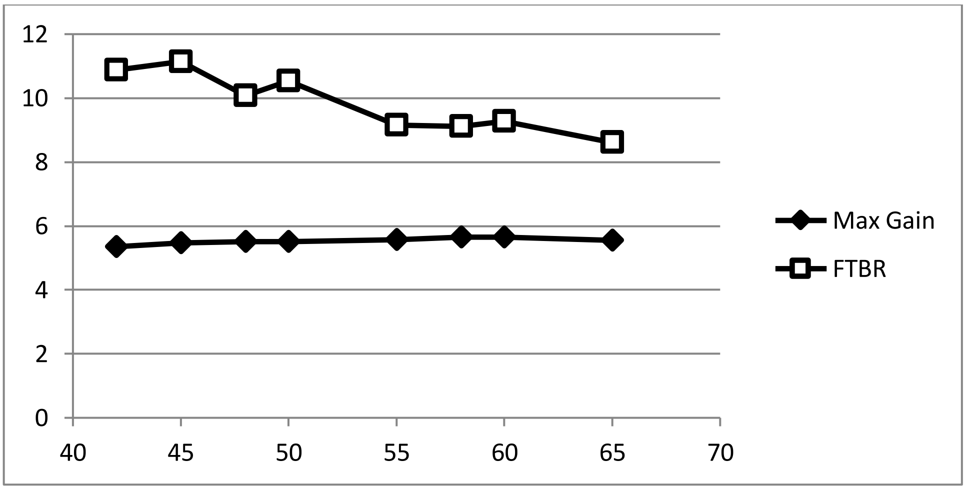


Figure 12. The impact of the distance of metal rod and resonating conductor to the maximum gain of proposed antenna design

The distance between the metal elements and the centre of resonating conductor has minimal impact on the shape of radiation pattern. However, the impact is observed on the maximum gain and front-to-back ratio of the radiation pattern. The result from the preliminary analysis of radiation pattern is summarised in the graph below. The distance between the metal rod and the centre of resonating patch is varied and maximum gain for each case is obtained. From the graph shown in **Figure 12**, it can be seen that the maximum gain for the reconfigurable antenna is achieved when the metal rod is located 58 mm or one-fifth of the free-space wavelength from the centre of patch antenna. The maximum gain of the radiation pattern is improved when the distance increases. However, the highest front-to-back ratio is achieved when the metal rods are placed 42 mm from the centre patch.

4.3 Effect of increasing the number of metal rods

The number of directions covered by the proposed antenna depends on the number of metal rods attached to the patch antenna. As the shorted patch antenna has an Omni directional radiation pattern, the reconfigured radiation patterns are covering the entire plane but limited to the complexity of the

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

design as sown in **Figure 13**. For instance, to have a large number of directions covered on single plane means the number of metal rods attached to the antenna is also increased.

The position between the neighboring metal rods will be closer enough to introduce mutual coupling that will affect the fine beam resolution of the radiation pattern. **Table 1** below shows the number of metal rods attached to the antenna for different direction tuning. The expected main beam direction correlated to metal rod activated is also listed. The distance between the center of the patch and the metal rod is maintained. However, there is a direction error occurs in Case D, E and F, as more metal cylinders are attached around the patch antenna.

Table 1. Three Scheme comparing

Case	Number of rods	Expected beam	Actual beam	Reconfigurable direction
Case A	0	360	360	Omni direction
Case B	2	180	180	2
Case C	4	90	90	4
Case D	8	45	45	8
Case E	16	22.5	25	16
Case F	32	11.25	10	32

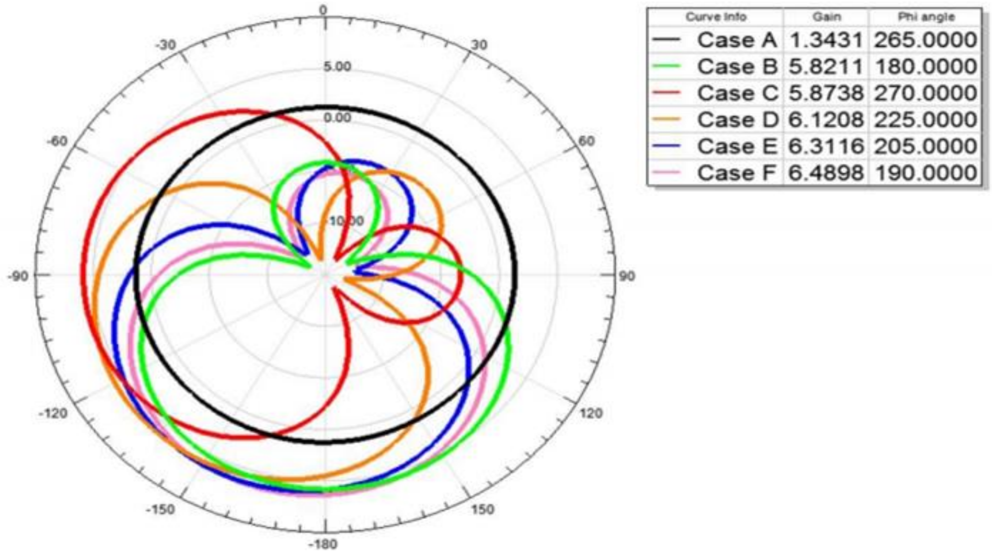


Figure 13. Radiation patterns for different number of metal rods attached to the shorted patch antenna.

5. Conclusion

Advanced wireless system necessitates an antenna with the ability to transmit and receive signal in all horizontal direction equally, and at the same time can be a directional antenna when preferred. Therefore, the construction of radiation pattern antenna is crucial to feed the demand. Reconfigurable antenna has a capability to change its parameter; i.e. frequency, radiation pattern and polarization, without significant change in antenna structure. Throughout this work, a patch antenna with an omnidirectional radiation pattern is designed and tested. A patch antenna is widely used because of its low-profile design.

A standard patch antenna has a directional radiation pattern. In the proposed antenna design, air dielectric is utilized to give the omnidirectional radiation pattern. By having an omnidirectional radiation pattern, it will be beneficial to incorporate the shorted patch antenna for an application that transmit or receive signal from wide variety of directions. The proposed antenna design also allows a full coverage of transmission in horizontal direction. Furthermore, the incorporation of shorting pin

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

resulted in a size reduction of the patch antenna. Integrating more than one shorted pin into the patch antenna ensure a more stable design.

The antenna in aforementioned chapter is modified, so that its radiation properties change by insertion of metal rod. The metal rod with full length of λ/2 acted as a reflector, thus gives significant change in the direction of radiation pattern. The optimal length and distance of the metal cylinder is acquired through parametric analysis in HFSS.

Acknowledgments

Special thanks go to my supervisor Prof. Wang Zhoupeng from shandong university of science and technology.

References

[1] B. A. Cetiner, G. Roqueta Crusats, L. Jofre, and N. Biyikli, "RF MEMS integrated frequency reconfigurable annular slot antenna," IEEE Trans. Antennas Propag., vol. 58, no. 3, pp. 626–632, 2010.

[2] D. Cheng and C. Chen, "Optimum element spacings for Yagi-Uda arrays," IEEE Trans. Antennas Propag., vol. 21, no. 5, pp. 615–623, Sep. 1973.

[3] C. Chen and D. Cheng, "Optimum element lengths for Yagi-Uda arrays," IEEE Trans. Antennas Propag., vol. 23, no. 1, pp. 8–15, Jan. 1975.

[4] A. A. Deshmukh and K. P. Ray, "Analysis of shorted-plate compact and broadband microstrip antenna," IEEE Antennas Propag. Mag., vol. 55, no. 6, pp. 100–113, 2013.

[5] M. Ye and P. Gao, "Back-to-back F semicircular antenna with frequency and pattern reconfigurability," Electron. Lett., vol. 51, no. 25, pp. 2073–2074, 2015.

[6] S. Nikolaou et al., "Pattern and Frequency Reconfigurable Annular Slot Antenna Using PIN Diodes," Antennas Propagation, IEEE Trans. (Volume54 , Issue 2), vol. 54, no. 2, pp. 439–448, 2006.

[7] S. Nikolaou, B. Kim, and P. Vryonides, "Reconfiguring Antenna Characteristics Using PIN Diodes," in Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference, 2009, pp. 3748–3752.

[8] W. Kang, S. Lee, K. Kim, S. Korea, and S. Korea, "A pattern-reconfigurable antenna using pin diodes," Microwave and Optical Technology Letters, vol. 53, no. 8, pp. 1883– 1887, May-2011.

[9] Z M. S. Shakhirul, M. Jusoh, Y. S. Lee, and C. R. Nurol Husna, "A Review of Reconfigurable Frequency Switching Technique on Micostrip Antenna," J. Phys. Conf. Ser., vol. 1019, p. 012042, Jun. 2018.

[10] N. Ramli, M. T. Ali, A. L. Yusof, M. T. Islam, and S. Muhamud-Kayut, "Reconfigurable Microstrip Stacked Array Antenna with Frequency and Pattern Characteristics," Prog. Electromagn. Res. C;2014, Vol. 49, p47, vol. 49, pp. 47–58, 2014.

[11] M. Shirazi, J. Huang, T. Li, and X. Gong, "A Switchable-Frequency Slot-Ring Antenna Element for Designing a Reconfigurable Array," IEEE Antennas Wirel. Propag. Lett., vol. 17, no. 2, pp. 229–233, 2018.

[12] M. Abou Al-alaa, H. A. Elsadek, E. A. Abdallah, and E. A. Hashish, "Pattern and frequency reconfigurable monopole disc antenna using PIN diodes and MEMS switches," Microw. Opt. Technol. Lett., vol. 56, no. 1, pp. 187–195, Jan. 2014.

[13] I. Ben Trad, J. M. Floc'H, H. Rmili, M. Drissi, and F. Choubani, "A planar reconfigurable radiation pattern dipole antenna with reflectors and directors for wireless communication applications," Int. J. Antennas Propag., vol. 2014, 2014. [26] J. Dong, Y. Li, and B. Zhang, "A survey on radiation pattern reconfigurable antennas," in 7th International Conference on Wireless Communications, Networking and Mobile Computing, WiCOM 2011, 2011, pp. 1–4.

[14] R. L. Haupt and M. Lanagan, "Reconfigurable antennas," IEEE Antennas Propag. Mag., vol. 55, no. 1, pp. 49–61, 2013.

[15] S. K. Sharma, F. Fideles, and A. Kalikond, "Planar Yagi-UDA antenna with reconfigurable radiation patterns," Microwave and Optical Technology Letters, vol. 55, no. 12, pp. 2946–2952, 2013.

[16] W. S. Kang, J. A. Park, and Y. J. Yoon, "Simple reconfigurable antenna with radiation pattern," Electron. Lett., vol. 44, no. 3, p. 182, 2008.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0030

[17] Zhan Shi, Ruping Zheng, Jun Ding, and Chenjiang Guo, "A Novel Pattern Reconfigurable Antenna Using Switched Printed Elements," IEEE Antennas Wirel. Propag. Lett., vol. 11, pp. 1100–1103, 2012.

[18] T. Aboufoul, C. Parini, X. Chen, and A. Alomainy, "Pattern-Reconfigurable Planar Circular Ultra-Wideband Monopole Antenna," IEEE Trans. Antennas Propag., vol. 61, no. 10, pp. 4973–4980, Oct. 2013.

[19] L. Ge, M. Li, J. Wang, and H. Gu, "Unidirectional Dual-Band Stacked Patch Antenna with Independent Frequency Reconfiguration," IEEE Antennas Wirel. Propag. Lett., vol. 16, pp. 113–116, 2017.

[20] O. Bayraktar, O. A. Civi, and T. Akin, "Beam switching reflectarray monolithically integrated with RF MEMS switches," IEEE Trans. Antennas Propag., vol. 60, no. 2 PART 2, pp. 854–862, 2012.