A Review on Different Feeding Methods of Wideband Circularly Polarized Antenna

Aniket Gunjal and Sumit Kumar

January 13, 2020

A Review on Different Feeding Methods of Wideband Circularly Polarized Antenna

Aniket Gunjal[1]
Electronics & Telecommunication Department
Symbiosis Institute of Technology
Symbiosis International (Deemed University), Pune, India
aniketgunjal89@gmail.com

Sumit kumar[2]
Electronics & Telecommunication Department
Symbiosis Institute of Technology
Symbiosis International (Deemed University), Pune, India
er.sumitkumar21@gmail.com

Abstract—This paper gives the overall idea of wideband circularly polarized antenna. The main objective of this review paper is to find how the circular polarization is achieved. There are different feeding methods for designing circularly polarized antennas such as single feed method, dual feed method, and sequential feeding method. This methods are useful to get good omnidirectional radiation pattern. Single feed method has some drawbacks. It has low axial ratio bandwidth than dual feed method. Further, in order to enhance the antenna performance axial ratio bandwidth improvement is necessary. Because of some limitations of linearly polarized antenna such as cross coupled radiation problem the circularly polarized antennas get certain attention as it overcomes many major drawbacks of linearly polarized antennas.

Keywords— Circular Polarization (CP), Feed Lines, Axial Ratio Bandwidth (ARBW), Gain, Radiation Pattern, Dielectric Resonator Antenna (DRA)

I. INTRODUCTION

The antenna polarization is one of the most important key in modern antenna designing [26]. Antennas can be linearly polarized or circularly polarized type. An antenna typically converts input frequency electric current into radio waves and these emitted waves by the antenna travels into the space. Polarization of antenna is important because it indicates the electric field vector of radio wave propagation. The transmitted waves are either linearly polarized or circularly polarized wave. Circularly polarized antennas having major advantages over linearly polarized antennas [22].The transmitted signal by the linearly polarized antenna leads to fading as it strikes on object or obstacles between them. This causes slight tilting of wave from its direction. The signal fading occurs due the change in phase of the transmitted signal. As the antenna having reciprocity property if the vertically polarized antenna act as the transmitter then the electric field vector is parallel to the earth's surface and if the receiver antenna is horizontally polarized then the electric field vector is perpendicular to the earth's surface that causes cross coupling issues. The circularly polarized antennas can reduce the effect of cross coupled radiation easily. The omnidirectional radiation pattern covers both the horizontally polarized & vertically polarized electric field vectors. The linearly polarized antennas require more attention on the orientation of electric field vector than the circularly polarized antennas. Because of these advantages of circular polarized antennas over linearly polarized antennas it is mainly used in satellite applications, mobile applications, wireless sensor applications, WI-Max applications, WLAN applications etc.[21]. This paper is mainly focused on different feeding methods for circular polarization. In single feed method of antenna designing there is a requirement of altering the shape of patch such as conical patch, slotted patch etc. Single feed network is easy to implement but it has some major drawbacks of having lower gain & low 3-dB ARBW [21].The drawback of single feed method has overcome by the dual feed arrangement of feed lines. Both the feed ports are orthogonal having approximately 90^0 phase difference between them but having equal amplitude. The axial ratio bandwidth is improved by using dual feed type of antennas. DRA has many features such as high efficiency, low dielectric loss etc. [52,59].The dielectric resonator antennas gives better performance in terms of as return loss, good isolation between ports, efficiency, impedance bandwidth, gain & axial ratio bandwidth of antenna.

II. SINGLE POINT FEED CIRCULARLY POLARIZED ANTENNA

A compact broadband wide-slot circular polarization (CP) antenna was reported. It shows that the antenna having feed line which acts as a simple monopole & back etched ground structure is responsible for wider bandwidth. An high impedance inverted L shaped strip is placed near the conducting feed line so that it creates an equal amplitude & orthogonal phase difference to generate CP waves.Further, bandwidth enhancement is done by simply changing the CPW length which is asymmetrical. This asymmetrical CPW structure also improves axial ratio of the antenna. With this technique the antenna gives wider BW of 89% & AR of 81% is achieved [1].

In this geometry, the asymmetric feed line is orthogonally placed with T shaped ground stub & two different L shaped stubs are placed at the right corner of the patch. Because of the two L shaped stubs there is a drastic change in the ARBW. The results show good AR BW typically 58.08%[2].

An inverted U shaped patch [3] is employed with an angle of 45^0 in order to generate CP modes. A slot is added at the center of the patch which acts as a lumped capacitor. As a result another CP mode is generated. These two CP modes are close enough which ultimately improves the ARBW of the antenna. The measured ARBW is 33.3%.

By employing the current carrying stub at the ground plane the orthogonal mode is improved. This strip-line length has a significant effect on the circular polarization. This strip line in addition gives the certain level of good ARBW approximately 19%. A wider portion is placed between the inverted L ground strip & straight conducting strip for further improving ARBW. When port 1 is excited it exhibits RHCP type of polarization similarly if port 2 is excited it gives LHCP waves. Because of the antenna symmetry return loss and CP wave radiation is similar for both ports [4].

The λ\2 dipole antenna forms driven element. The split ring resonator [5] is placed in the middle of dipole & reflectors. SRR is introduced to obtain new resonant frequency. At lower frequency the SRR act as a director & at higher frequency the current get coupled over SRR's making SRR to act as driven element.The antenna gain is enhanced by simply adding split rings resonators which further improves the dual band performance of antenna. The peak gain of antenna is 6.14dBi & 6.8dBi respectively.

The dielectric resonator antenna (DR) has two layers. The substrate is located at the middle portion. The antenna is excited by using cross line slots placed at ground plane. The shorter lengths of crossed line slots are varied to obtain better CP bandwidth [9]. The result shows dual band response as the two quasi modes are generated. The LHCP gain of the antenna is 5.5 dBi & 6.0 dBi respectively for two different bands. The ARBW of the antenna is 9.7% & 20.0% respectively.

No. of Antenna Elements	**Patch Shape**	**Frequency (GHz)**	**Feed Type**	**Axial Ratio Bandwidth (%) & GAIN(dBic)**	**Ref.**
1	Circular	9.4	SIW Feed	2.7 & 6.6	[11]
1	U Shaped	5.4	Micro strip	20.80 & 5.19	[12]
1	Rectangular	2.4 & 3.3	CPW Feed	27.45, 7.1 & 2.5	[13]
1	Triangular	2.4	Probe	1.3 & 4.0	[14]
1	Rectangular	2.4	Probe	2.8 & 6.38	[15]
1	Rectangular	2.4	Cross-Slot	4.6 & 8.0	[23]
1	Rectangular	850 MHz	Probe Feed	13.4 & 7.0	[24]
1	Fractal Curve	2.5	Probe Feed	1.6 & 6.0	[25]
1	Rectangular DRA	7.5	Probe Feed	10.6 ,13.5 & --	[27]
1	Circular	2.4 & 5.8	Micro strip	13.3, 16.9 & 2.3,3.1	[28]
6X6	Rectangular stacked Patch	2.16	Probe Feed	12.26 & 4.7	[33]
1	E –Shaped Patch	403.5-MHz & 2.45	CPW Feed	-- & −18.5 , -19.5	[36]
1	C –Shaped	2.3	CPW Feed	-- & -16.5	[37]
1	Square Slot patch	3.8	CPW Feed	56 & 3.2	[38]
8	Square Patch	10.1	SIW Feed	2.17, 1.78 & 11.6,11.2	[39]
1	Luneburg lens	30.6	Patch Feed	1.96 & 13.4	[40]
1	Circular	2.5	Probe	2.3 & 4.4	[41]
1	L-Shape	3 & 5.5	Micro strip	37.4 ,16.3 & 4.3,3.3	[42]
3X3	Rectangular	5.7	Probe	2.8 & 6.9	[43]
1	Rectangular	5.5	Probe	2.54 & 4.17	[44]
1	C-shaped slot	4.5	Off-Center	115.2 & 4.51	[46]
1X4	Square patch	10.2	SIW Feed	10.9 & 10.5	[51]

Table 1: Comparison Table for Single Feed type of CP Antennas

III. MULTI POINT FEED CIRCULARLY POLARIZED ANTENNA

The two circular chamfers [6] are placed at the ground surface area which is used to reduce the difference between two resonant frequency modes for improving amplitude ratio & CP radiation pattern of antenna. The position of two feed lines is changed in X- direction (upward) in order to get dual band response. The width of the feed line is adjusted such that wider impedance bandwidth is obtained. The results shows that there is large improvement in 3-dB ARBW (110.5%) as well as gain (4.5dBic) of the antenna is also enhanced.

The asymmetric feed lines are decoupled by inserting a strip line in between them [7].This is necessary to reduce the effect of induced current from both the ports while the two ports are orthogonal to each other. By protruding the inverted L-shaped strips (ILSS) & L-shaped strips (LSS) on the top left corner of the hexagonal patch further broaden the AR of antenna. As a result ARBW is 80.7% & peak gain is 3.8dBic.

In this [8], the T shaped feed lines are employed such that it creates circularly polarized waves with orthogonal phase difference between them but having equal amplitude ratio. If we excite one port other port acts as matched or terminated to 50 ohm impedances. In addition an inverted L shaped ground strip is inserted at the left corner of the patch to improve the ARBW of antenna. By inserting extra straight conducting strips ARBW is improved as it produces multiple resonant modes. By introducing a wider portion between the inverted L strip & straight lines fine tuning of ARBW is done. The result gives ARBW of 59.65% & highest peak gain of 4 dBic is achieved.

In [10], two cylindrical patches are placed over each other with the sufficient height between them. These two circular patches are fixed by a metallic line. The air gap acts as a dielectric material. The two orthogonally placed feeding lines are connected to circular radiators to achieve the CP radiation of antenna. With the increase in the height (h1) between patch & ground plane the AR & BW is modified. The gain of antenna is 15.5 dBic & ARBW is 11%.

No. of Antenna Elements	Patch Shape	Frequency (GHz)	Feed Type	ARBW (%) & GAIN (dBic)	Ref.
1	Horn shape	12.5	Micro strip	11.2 & 4.7	[16]
1	Rectangular	2.15	Micro strip	31.3 & 7.01	[17]
4	Rectangular	5.3	Micr strip	11.5 & 11.3	[18]
4	Circular	5.3& 8.2	Micro strip	13.2, 12.8 & 14.5,17.5	[19]
1	Semicircular	2.4	CPW Feed	102.6 & 5.01	[20]
8X8 Array	Square	60	SIW Feed	23 & 25.8	[30]
1	L-Shaped	2.4 & 5.5	Horse shoe Shape slot	72.5,56.0 & 4.0,3.05	[31]
1	Square	2.5	Probe	25.1 & 7	[45]

Table 2: Comparison Table for Dual Feed Type of CP Antennas

IV. CIRCULAR POLARIZATION USING SEQUENTIAL FEED NETWORK

In [29], the antenna consist of three layers in which the upper layer contains impedance matched coupled lines which acts a dipole and the lower layer is composed of coupled line divider & phase line shift network. The middle layer forms matched coupled network. The inter-digital type of network is formed in the upper layer is used to get very strong mutual coupling between the tightly loaded diploes. The coupled line & phase shifting network is responsible for a wide CP resonance. The ARBW is 77% & peak gain of 10.4 dBic.

In [32], the feed line structure is formed by adding phase shifter & branch line coupler. The rat ring coupler gives 180^0 shifting of phase. The current gets distributed among two branch line coupler to provide two paths for the current having equal amplitude & 90^0 phase difference between them. This array slots are present exactly on the ground portion below radiating patch elements. The antenna's AR Bandwidth is 3.04%. & gain is 10.84 dBic.

In [34], it shows that the four crossed dipole act as a PIN diodes. One end of diode is connected to feeding network and other end is coupled to ground plane via holes. The cross dipoles are used to achieve polarization selectivity. The port 2 is the longest among all these ports to make 90^0 phase difference with other ports. The gain of the antenna is 5.0dBic.

No. of Antenna Elements	Patch Shape	Frequency (GHz)	Feed Type	ARBW (%) & GAIN (dBic)	Ref.
2	Umbrella Shape	1.5	Probe	55.6 & 3.0	[35]
2X2	Disc Shape	5.8	Coaxial Feed	-- & 10.5	[47]
2	Tapered Slot	1.85	CPW Feed	107 & 8	[48]
1	Inverted -F	900 MHz	Coaxial Feed	14.7 & 2.1	[49]
2X2	Square	2.4	Microstrip Line	5 & 5.8	[50]

Table 3: Comparison Table for Sequential Feed Type of CP Antennas

V. CONCLUSION

This paper gives a brief idea about the different feeding methods of circularly polarized antennas.The dual feed method gives good polarization diversity. It is also found that dual feed method gives better axial ratio bandwidth than that of single feeding method. The enhancement in axial ratio bandwidth and gain is necessary as the researchers gives more attention to both the parameters for developing circularly polarized antennas. Higher the axial ratio bandwidth means better the circular radiation pattern of antenna. Polarization purity of antenna depends upon the 3dB-axial ratio bandwidth. The selected papers are studied & it is found that the circularly polarized antenna overcomes many limitations of linearly polarized antennas such as cross coupled radiation is reduced because the circularly polarized antenna having omnidirectional radiation pattern. The feed width & its position has a significant effect on impedance bandwidth of antenna.

REFERENCES

[1] Ullah, U., & Koziel, S. (2019).A Geometrically Simple Compact Wideband Circularly Polarized Antenna. IEEE Antennas and Wireless Propagation Letters, 18(6), 1179-1183.

[2] Midya, M., Bhattacharjee, S., & Mitra, M. (2018). Pair of grounded L strips loaded broadband circularly polarised square slot antenna with enhanced axial ratio bandwidth. Electronics Letters, 54(15), 917-918.

[3] Hoang, T. V., Le, T. T., & Park, H. C. (2016). Bandwidth improvement of a circularly polarized printed monopole antenna using a lumped capacitor. Electronics Letters, 52(13), 1091-1092

[4] Khalily, M., Kamarudin, M. R., & Danesh, S. (2013, July). Planar wideband circularly polarized dielectric resonator antenna. In 2013 IEEE Antennas and Propagation Society International Symposium (APSURSI) (pp. 1238-1239). IEEE

[5] Chen, Z., Zeng, M., Andrenko, A. S., Xu, Y., & Tan, H. Z. (2019). A dual-band high-gain quasi-Yagi antenna with split-ring resonators for radio frequency energy harvesting.Microwave and Optical Technology Letters, 61(9), 2174-2181

[6] Xu, R., Li, J. Y., Yang, J. J., Wei, K., & Qi, Y. X. (2017). A design of U-shaped slot antenna with broadband dual circularly polarized radiation.IEEE Transactions on Antennas and Propagation, 65(6), 3217-322.

[7] Chandu, D. S., & Karthikeyan, S. S. (2017).A novel broadband dual circularly polarized microstrip-fed monopole antenna.IEEE Transactions on Antennas and Propagation, 65(3), 1410-1415.

[8] Saini, R. K., & Dwari, S. (2015). A broadband dual circularly polarized square slot antenna.IEEE Transactions on Antennas and Propagation, 64(1), 290-294.

[9] Zou, M., & Pan, J. (2015). Wide dual-band circularly polarized stacked rectangular dielectric resonator antenna. IEEE Antennas and Wireless Propagation Letters, 15, 1140-1143.

[10] Zhao, X., Huang, Y., Li, J., Zhang, Q., & Wen, G. (2017). Wideband high gain circularly polarized UHF RFID reader microstrip antenna and array.AEU-International Journal of Electronics and Communications, 77, 76-81.

[11] Kumar,A. & Raghavan, S.(2017).Design of a broadband planar cavity-backed circular patch antenna. AEU-International Journal of Electronics and Communications, 82, 413-419.

[12] Yadav,A.,Singh, V. K., & Mohan, H. (2019).Design of a U-shaped circularly polarized wearable antenna with DGS on a fabric substrate for WLAN and C-band applications. Journal of Computational Electronics, 1-7.

[13] Saini,R.K.,Dwari,S., & Mandal,M.K. (2017). CPW-fed dual-band dual-sense circularly polarized monopole antenna. IEEE Antennas and Wireless Propagation Letters, 16, 2497-2500.

[14] Pasumarthy,N.R.,& Yagateela,P.R. (2016). Compact single feed circularly polarized Koch island microstrip antenna AEU-International Journal of Electronics and Communications, 70(11), 1543-1550.

[15] Wang, S., Zhang, X., Zhu, L., & Wu, W.(2018). Single-fed wide-beamwidth circularly polarized patch antenna using dual-function 3-d printed substrate. Ieee Antennas And Wireless Propagation Letters, 17(4),649-653.

[16] Kumar, K., Dwari, S., & Mandal, M. K. (2017). Broadband dual circularly polarized substrate integrated waveguide antenna. IEEE Antennas and Wireless Propagation Letters, 16, 2971-2974.

[17] Liu, S., Yang, D., & Pan, J. (2019). A Low-Profile Broadband Dual Circularly Polarized Metasurface Antenna. IEEE Antennas and Wireless Propagation Letters.

[18] Mao, C. X., Gao, S. S., Wang, Y., & Sumantyo, J. T. S. (2017). Compact broadband dual-sense circularly polarized microstrip antenna/array with enhanced isolation. IEEE Transactions on Antennas and Propagation, 65(12), 7073-7082.

[19] Mao, C. X., Gao, S., Wang, Y., Chu, Q. X., & Yang, X. X. (2017). Dual-Band Circularly Polarized Shared-Aperture Array for $ C $-/$ X $-Band Satellite Communications. IEEE Transactions on Antennas and Propagation, 65(10), 5171-517

[20] Li, Z., Zhu, X., & Yin, C. (2019).CPW-fed ultra-wideband slot antenna with broadband dual circular polarization. AEU-International Journal of Electronics and Communications, 98, 191-198.

[21] S Gao, Q Luo, F Zhu,Circularly Polarized Antennas, Wiley-IEEE Press, Ed. 1, 2014.

[22] Ullah, U., Ain,M.F., & Ahmad,Z.A.(2017).A review of wideband circularly polarized dielectric resonator antennas. China Communications, 14(6), 65-79.

[23] Kim, H., Lee, B. M., & Yoon, Y. J. (2003). A single-feeding circularly polarized microstrip antenna with the effect of hybrid feeding. IEEE Antennas and Wireless Propagation Letters, 2, 74-77.

[24] Qing, X., & Chen, Z. N. (2013). A wideband circularly polarized stacked slotted microstrip patch antenna. IEEE Antennas and Propagation Magazine, 55(6), 84-99.

[25] Rao, P. N., & Sarma, N. V. S. N. (2008). Fractal boundary circularly polarised single feed microstrip antenna. Electronics Letters, 44(12), 713-714.

[26] Toh, B. Y., Cahill, R., & Fusco, V. F. (2003). Understanding and measuring circular polarization. IEEE Transactions on Education, 46(3), 313-318.

[27] Lim, E. H., & Leung, K. W. (2008, July). Compact wideband circularly polarized dielectric resonator antenna with an underlaid hybrid coupler. In 2008 IEEE Antennas and Propagation Society International Symposium (pp. 1-4). IEEE.

[28] Ge, L., Su, H. L., Lu, J. Y., & Ku, C. (2017). Single-layer dual-broadband circularly polarised annular-slot antenna for WLAN applications. IET Microwaves, Antennas & Propagation, 12(1), 99-107.

[29] Yang, L., Zhang, Z. Y., Wu, D., Fu, G., & Yan, Z. (2017). Wideband circularly polarised antenna based on tightly coupling effect. Electronics Letters, 53(7), 448-450.

[30] Zhao, Y., & Luk, K. M. (2018). Dual circular-polarized SIW-fed high-gain scalable antenna array for 60 GHz applications. IEEE Transactions on Antennas and Propagation, 66(3), 1288-1298.

[31] Xu, R., Li, J. Y., Liu, J., Zhou, S. G., Xing, Z. J., & Wei, K. (2018). A design of dual-wideband planar printed antenna for circular polarization diversity by combining slot and monopole modes. IEEE Transactions on Antennas and Propagation, 66(8), 4326-4331.

[32] Siahcheshm,A.,Nourinia,J., Ghobadi, C., Karamirad, M., & Mohammadi, B. (2017). A broadband circularly polarized cavity-backed rchimedean spiral array antenna for C-band applications. AEU-International Journal of Electronics and Communications, 81, 218-226.

[33] Safari Dehnavi, M., Razavi, S. M. J., & Mohseni Armaki, S. H. (2019). Improvement of the gain and the axial ratio of a circular polarization microstrip antenna by using a metamaterial superstrate. Microwave and Optical Technology Letters, 61(10), 2261-2267.

[34] Wu, H. F., Wei, Y. H., Chen, T. R., & Row, J. S. (2019).Quad-polarization reconfigurable antenna with wideband operation. Microwave and Optical Technology Letters.

[35] Yan,Y.D., Jiao, Y. C., Weng, Z., & Zhang, C. (2019). An umbrella-shaped broadband circularly polarized antenna with wide beamwidth for global navigation satellite systems applications. Microwave and Optical Technology Letters, 61(11), 2455-2462.

[36] Yeap, K., Voon, C., Hiraguri, T., & Nisar, H. (2019). A compact dual-band implantable antenna for medical telemetry. Microwave and Optical Technology Letters, 61(9), 2105-2109.

[37] Bhattacharjee, S., Maity, S., Chaudhuri, S. R. B., & Mitra, M. (2018). Metamaterial-inspired wideband biocompatible antenna for implantable applications. IET Microwaves, Antennas & Propagation, 12(11), 1799-1805.

[38] Sadeghi,P.,Nourinia,J.,& Ghobadi, C. (2016). Square slot antenna with two spiral slots loaded for broadband circular polarisation. Electronics Letters, 52(10), 787-788.

[39] Lu, L., Jiao, Y. C., Weng, Z. B., Ni, T., & Zhang, C. (2016).Bidirectional circularly-polarised loop linear array fed by slotted SIW. Electronics Letters, 52(14), 1193-1194.

[40] Shi, Z., Yang, S., Qu, S. W., & Chen, Y. (2016).Circularly polarised planar Luneberg lens antenna for mm-wave wireless communication. Electronics Letters, 52(15), 1281-1282.

[41] Mathew, S., Ameen, M., Jayakrishnan, M.P., Mohanan,P.,&Vasudevan,K.(2016).Compact dual polarised V slit, stub and slot embedded circular patch antenna for UMTS/ Wi MAX/WLAN applications. Electronics Letters, 52(17), 1425-1426.

[42] Rui, X., Li, J., & Wei, K. (2016). Dual-band dual-sense circularly polarised square slot antenna with simple structure. Electronics Letters, 52(8), 578-580.

[43] Liang, Z., Ouyang, J.,& Yang, F. (2018). Low-profile wideband circularly polarised single-layer metasurface antenna. Electronics Letters, 54(24), 1362-1364.

[44] Ameen, M.,& Chaudhary, R. K. (2018). Metamaterial-based circularly polarised antenna employing ENG-TL with enhanced bandwidth for WLAN applications. Electronics Letters, 54(20), 1152-1154.

[45] Wu, J.,Yang, H., & Yin, Y. Z. (2014). Dual circularly polarized antenna with suspended strip line feeding. Progress In Electromagnetics Research, 55, 9-16.

[46] Xu, R., Li, J., Liu, J., Zhou, S. G., & Wei, K. (2018). UWB circularly polarised slot antenna with modified

ground plane and L-shaped radiator. Electronics Letters, 54(15), 918-920.

[47] Maddio, S. (2017). Parasitic-enhanced circularly polarised sequential antenna array for dedicated short-range communication applications at 5.8 GHz. Electronics Letters, 53(13), 824-826.

[48] Ding, X., Zhao, Z., Yang, Y., Nie, Z., & Liu, Q. H. (2018). A compact unidirectional ultra-wideband circularly polarized antenna based on crossed tapered slot radiation elements. IEEE Transactions on Antennas and Propagation, 66(12), 7353-7358.

[49] Sun, L., Li, Y., Zhang, Z., & Feng, Z. (2019). Low-Profile Compact Circularly Polarized Slot-Etched PIFA Using Even and Odd Modes. IEEE Transactions on Antennas and Propagation, 67(6), 4189-4194.

[50] Nosrati, M., & Tavassolian, N. (2017). Effects of antenna charcteristics on the performance of heart rate monitoring radar systems. IEEE Transactions on Antennas and Propagation, 65(6), 3296-3301.

[51] Sabri, L., Amiri, N., & Forooraghi, K. (2017).SIW-fed microstrip patch antenna array for circular polarization.International Journal of Microwave and Wireless Technologies, 9(9), 1877-1881.

[52] Ullah, U., Ali, W. F. F. W., Ain, M. F., Mahyuddin, N. M., & Ahmad, Z. A. (2015). Design of a novel dielectric resonator antenna using MgTiO3–CoTiO3 for wideband applications. Materials & Design, 85, 396-403.

[53] Fang, X., Leung, K. W., & Lim, E. H. (2014). Singly-fed dual-band circularly polarized dielectric resonator antenna. IEEE antennas and wireless propagation letters, 13, 995-998.

[54] Yang, L. S., Yang, L., Zhu, Y. A., Yoshitomi, K., & Kanaya, H. (2019). Polarization reconfigurable slot antenna for 5.8 GHz wireless applications. AEU-International Journal of Electronics and Communications, 101, 27-32.

[55] Kaur, M., & Sivia, J. S. (2019). Minkowski, Giuseppe Peano and Koch curves based design of compact hybrid fractal antenna for biomedical applications using ANN and PSO. AEU-International Journal of Electronics and Communications, 99, 14-24.

[56] Rao, M. V., Madhav, B. T. P., Anilkumar, T., & Nadh, B. P. (2018). Metamaterial inspired quad band circularly polarized antenna for WLAN/ISM/Bluetooth/WiMAX and satellite communication applications. AEU-International Journal of Electronics and Communications, 97, 229-241.

[57] Ranjan, P., Raj, S., Upadhyay, G., Tripathi, S.,& Tripathi, V. S. (2017). Circularly slotted flower shaped UWB filtering antenna with high peak gain performance. AEU-International Journal of Electronics and Communications, 81, 209-217.

[58] Ta, S. X., Nguyen, T. H. Y., Nguyen, K. K., & Dao‐Ngoc, C. (2019). Bandwidth‐ enhancement of circularly‐polarized fabry‐perot antenna using single‐layer partially reflective surface. International Journal of RF and Microwave Computer‐Aided Engineering, 29(8), e21774.

[59] Bhadoria, B. and S. Kumar, “A novel omnidirectional triangular patch antenna array using dolphchebyshev current distribution for C-band applications,”Progress In Electromagnetics Research M,Vol. 71, 75–84, 2018