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Optimized Design of a Microstrip Patch Antenna for Radar Applications

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ABSTRACT:

Radars demand low profile and light weight antenna subsystems. Microstrip antennas possess these characteristics and serve as an alternative to the bulky and heavy weight reflector/slotted waveguide array antennas, thus an ideal choice for radars. Here, a single line fed microstrip antenna with pierced corners is designed. This antenna has improved parameters compared to the conventional square microstrip antenna. The main problem encountered is in designing the patch antenna with optimum values for various antenna parameters. In order to solve this problem, an alternative solution used is Artificial Neural Networks (ANN). The antenna is also optimized using Particle Swarm Optimization (PSO). The parameters considered in all the cases are return loss (S11) and VSWR which was designed using FEKO software. The designed antennas are found to radiate in the C-band, which covers frequencies in the range 5-8GHz, applicable in most of the modern radars. The simulation design is carried out using CADFEKO suite.

KEYWORDS:

Radar; Microstrip patch antenna; FEKO; Design; Artificial neural network; Optimization

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1. Introduction

A microstrip or patch antenna is a low profile antenna that has a lot of advantages and widely used in many wireless applications. It is lightweight, inexpensive and easy to integrate with electronic components. Refs. [2] and [3] state that these antennas are easy to fabricate with the help of cheap substrate materials. Microstrip antennas offer many advantages like low profile, light weight, easy integration with microwave devices in planar or non-planar surfaces, inexpensive to manufacture. These advantages make them quite popular among a large number of users. The microstrip patch antenna has several applications ranging from radio frequency and satellite communication, military devices, radio frequency identification (RFID), radars, etc. Komanduri and Jackson [3] proposed a general method for reducing the field excitation due to surface-wave components of a microstrip antenna. The proposed approach is based on a theorem called the surface wave reduction (SWaR) theorem. The method proposed here uses a proper method to fill the space between the patch and the ground plane.

The material which is used to fill is properly selected to eliminate the excitation of the surface wave with lowest cut-off frequency. An ultra-compact antenna with circular polarization, using a four array of folded-shorted patches was designed by Podilchak and Caillet [4]. But, the main design challenge of the array was that it had to achieve miniaturization. Another microstrip antenna was proposed for wireless applications, consisting of two radiating patch elements one in rectangular shape and the other a triangular patch element. These two elements were interconnected by another patch B1 element step sized. Antenna far field radiation characteristics can be changed by properly selecting its shape. Here the corners are truncated to improve the field potential. It shows that the behaviour of the antenna is greatly influenced by the position of patch element B1, length of the triangle, size of ground plane and length of rectangular patch which, leads to better return loss and higher impedance. Also microstrip patch antenna plays its crucial role in medical diagnostics and treatment of several diseases [21].

Sharma and Singh [5] presented the simulation results of a rectangular microstrip patch antenna in the terahertz (THz) frequency range. The simulated results obtained for gain, radiation efficiency and impedance bandwidth with and without shorting post configurations, were discussed. However, one of the principle challenges faced was that modern wireless communication in the terahertz range could only be used for short distances. This was because in the case of long distance communication at terahertz frequency, a phenomenon occurred during propagation of electromagnetic waves through the atmosphere. [6] Deals with the process of bandwidth enhancement in antennas. Artificial Neural Networks (ANN) have been used for the determination of resonant frequency, as in [7]. The design and study of a wideband one-feed circularly polarized microstrip antenna, square shaped microstrip antenna for circular polarization and a circular polarized stacked with annular-ring structured antenna are described in [8-10].

A circularly polarized microstrip antenna for GPS applications is designed and optimized for the antenna parameters in [11]. In this paper, we propose various techniques that are implemented to improve the antenna parameters like VSWR and the reflection coefficient. First, we deal with the design of a circularly polarized one-feed square microstrip antenna by symmetrically piercing a pair in the corners of the patch. Then, certain equations are given through which artificial neural networks, are used to determine the patch dimensions of the particular antenna to be designed.

2. Antenna design

2.1. Truncated square microstrip antenna design

The configuration of one feed circularly polarized square microstrip antenna, with pierced corners is exhibited in Fig. 1. The square patch design has a dimension of equal length L which is etched into a dielectric substrate material with a thickness of H, loss tangent of tan δ, and relative permittivity of εr. The pierced patch corners as shown in Fig. 1(a) are symmetrically pierced in order to produce circularly polarized radiations. The conditions of circularly polarized operation of the one-feed microstrip antenna with pierced corners can be arranged as follows:

$$L_t = L / \sqrt{2Q_t} \quad (1)$$

$$f_0 = f_r (1 + 1 / 4Q_t) \quad (2)$$

Where L_t is the dimension of the pierced length, Q_t being the total quality factor, f_0 the operating frequency and f_r the resonant frequency of the square microstrip antenna.

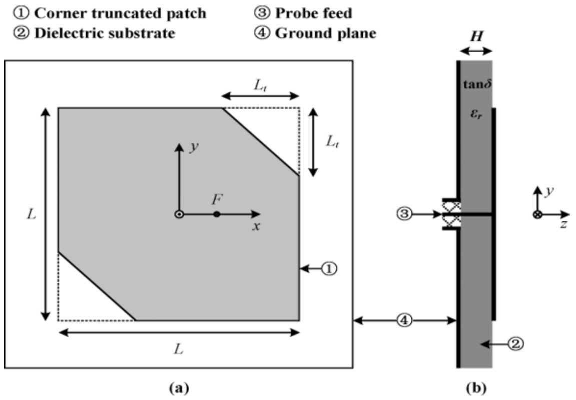

Fig. 1: Configuration of a single feed square microstrip antenna with pierced corners: (a) top view (b) side view

The formula for calculating the resonant frequency for a square microstrip antenna is given as:

$$f_r = c / 2L_e \sqrt{\varepsilon_r} \quad (3)$$

Where c is the velocity of electromagnetic waves in free space, and L_e the effective length of the square patch. But what is being noted is, when the required operating frequency f_0 and the supplied substrate (ε_r, tan δ, H) are given, the physical dimensions of one feed circularly polarized square shaped microstrip patch antenna with pierced corners (L and L_t) cannot be directly obtained from Equations (1-3). To solve this problem, artificial neural networks can be used to model the nonlinear relation between [f_0, ε_r, tan δ, H] and [L, L_t]. Fig. 2 shows the CADFEKO model of a conventional square patch antenna with specifications: length of square patch = 31mm, length of the substrate = 50mm, height of substrate = 2.87mm, εr = 2.55, and frequency = 6GHz.

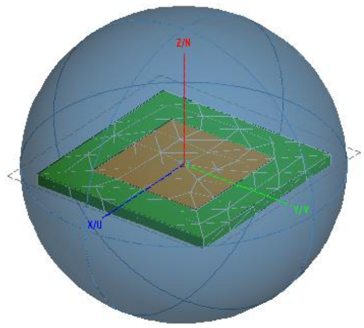

Fig. 2: Simulated model for square microstrip antenna

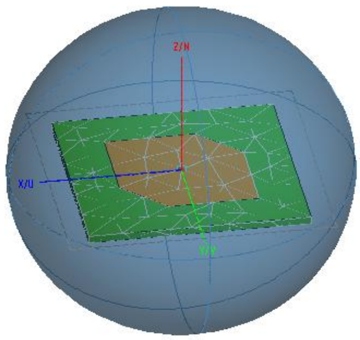

Fig. 3: Simulated model for square microstrip antenna with truncated corners

2.2. Truncated circular microstrip antenna design

We analyze the results for a circular patch antenna, by starting with a single conductive via and then we go on increasing the number of vias, on the patch antenna. All of these results are then to be compared with that of an ordinary circular patch antenna - with no vias at all, as shown in Fig. 1. We aim at studying how the increase in the number of conductive vias can affect the performance of a circular microstrip patch antenna. The simulated design of an ordinary circular patch antenna is shown in Fig. 4.

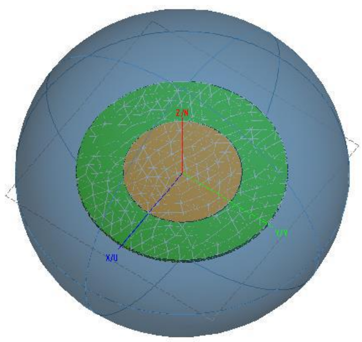

Fig. 4: Simulated model of an ordinary circular patch antenna

As a result, we analyze the results for a circular patch antenna, by starting with a single conductive via instead, and then we go on increasing the number of vias-on the patch antenna. Next, two conductive vias are introduced in the circular patch antenna. Let N be the total number of vias used in Fig. 5. Specifications are: N = 2, patch radius = 22.3mm, substrate radius = 40mm, substrate height = 3.17mm, frequency = 2.3GHz and dielectric constant = 2.2.

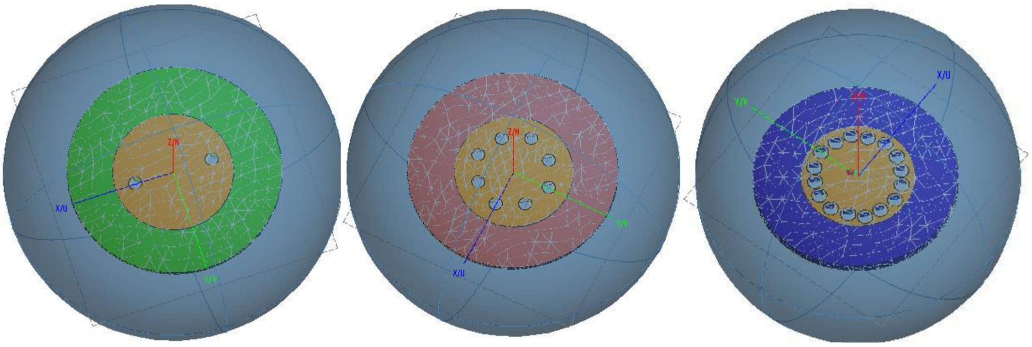

Fig. 5: Simulated model of a circular patch antenna using conductive vias, N = 2 (left), N = 8 (middle) and N = 16 (right)

2.3. ANN - based design for rectangular patch

ANNs are under the process of development for many years. But, ANNs provide fastness and flexibility for antenna modelling, simulation, and optimization, recently. Multilayer perceptron (MLP) is an important class of ANNs which is suitable for modelling high-dimensional and highly non correlated problems. An MLP consists of an input layer, an output layer and one or more hidden layers. The training algorithm selection is the best choice for this algorithm. The design of a rectangular patch antenna has been done using MLP, in [12]. A detailed study of multilayer perceptron neural networks has been conducted in [13]. Levenberg-Marquardt (LM) algorithm is used to train the MLPs for modelling. Fig. 4 gives an ANN-adopted synthesis model which is used for the design. The number of neurons in the hidden layers and the training time can be reduced when we use H / λ_g and τ_d instead of using H and tan δ as the inputs. H / λ_g and τ_d are calculated using the following equations:

$$H / \lambda_g = H f_0 \sqrt{\varepsilon_r} / c \quad (4)$$

$$T_d = -\log(\tan \delta) \quad (5)$$

The formulae (1-5) are now used to generate a whole range of possible values for ε_r, tan δ, H, and L. These equations were formulated in MATLAB software, to obtain the physical dimensions of the antenna, which were then used for the antenna design in FEKO. The range of obtaining values : $1 \leq \varepsilon_r \leq 12$, 10-4 ≤ tan δ ≤ 10-1.5, 0.2mm ≤ H ≤ 30.0mm, and 5mm ≤ L ≤ 150mm.

2.4. PSO - based design

The optimization technique used is Particle Swarm Optimization (PSO). The particle swarm optimization (PSO) is a robust computation technique based on the concept of movement and intelligence of swarms. All the optimization process was performed using the PSO tool of the program FEKO. Imagine a swarm of bees in a field. Their goal is to find in the field the location with the highest density of flowers. Without any knowledge of the field a priori, the bees begin in random locations with random velocities looking for flowers. Each bee can remember the locations that it found the most flowers, and somehow knows the locations where the other bees found an abundance of flowers. Torn between returning to the location where it had personally found the most flowers, or exploring the location reported by others to have the most flowers, the ambivalent bee accelerates in both directions altering its trajectory to fly somewhere between the two points depending on whether nostalgia or social influence dominates its decision bee might find a place with a higher concentration of flowers than it had found previously.

It would then be drawn to this new location as well as the location of the most flowers found by the whole swarm. Occasionally, one bee may fly over a place with more flowers than had been encountered by any bee in the swarm. The whole swarm would then be drawn towards that location in additional to their own personal discovery. In this way the bees explore the field: overflying locations of greatest concentration, then being pulled back toward them. Constantly, they are checking the territory they fly over against previously encountered locations of highest concentration, hoping to find the absolute highest concentration of flowers. Eventually, the bee's flight leads them to the one place in the field with the highest concentration of flowers. Soon, all the bees swarm around this point. Unable to find any points of higher flower concentration, they are continually drawn back to the highest flower concentration.

3. Results and discussion

As a result, ANNs have been successfully introduced for the synthesis and analysis of the one-feed circularly polarized square shaped microstrip antenna with pierced corners. To obtain better performance, faster convergence, and a simpler structure, artificial neural networks were trained using the Levenberg-Marquardt (LM) algorithm. The ratio of the amplitude of the reflected wave V_r to the amplitude of the incident wave V_i is known as the reflection coefficient, Γ, as follows,

$$\Gamma = V_r / V_i \quad (6)$$

Return loss is the negative of the magnitude of the reflection coefficient in dB. Since power is proportional to the square of the voltage, return loss is given by,

$$\text{Return loss (dB)} = -20\log10 \, |\Gamma| \quad (7)$$

For an antenna to be preferred, its return loss should be under -10dB. Here the loss is considerably reduced. The optimization techniques used further reduces the losses. Hence this antenna can well be used as a radar antenna as its frequency is within the band. Figs. 5-8 display the values of S11 obtained with a normal square microstrip antenna, square microstrip antenna with the ANN based microstrip antenna design, and PSO based design respectively.

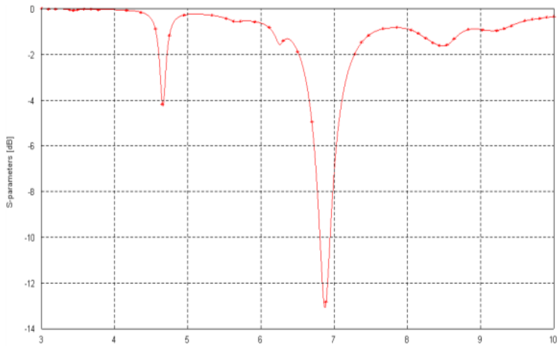

Fig. 6: S11 parameter graph of a square microstrip antenna with truncated corners

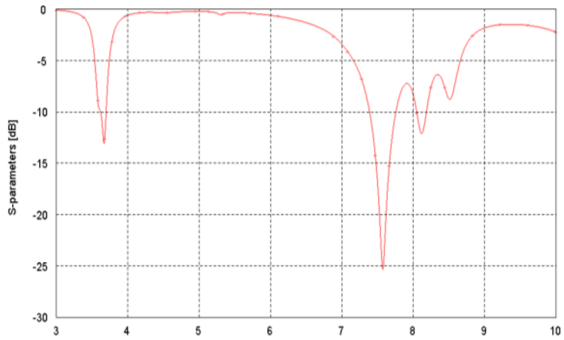

Fig. 7: S11 parameter graph of an ANN-based square microstrip antenna

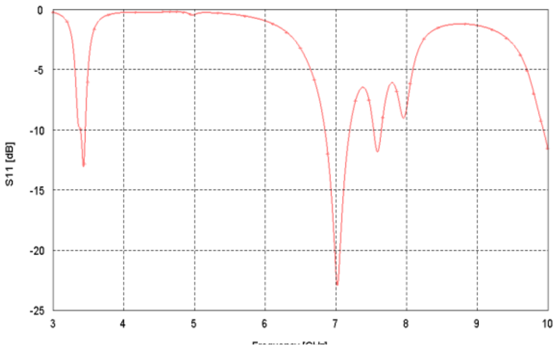

Fig. 8: S11 parameter graph of a PSO-based square microstrip antenna

Similarly, Figs. 9-11 display the values of VSWR obtained with a square microstrip antenna with truncated corners, with the ANN based microstrip antenna design, and PSO based design respectively. In all the cases, the VSWR is within its limit. For better clarity, we will now tabulate the values of the S11 and obtained VSWR.

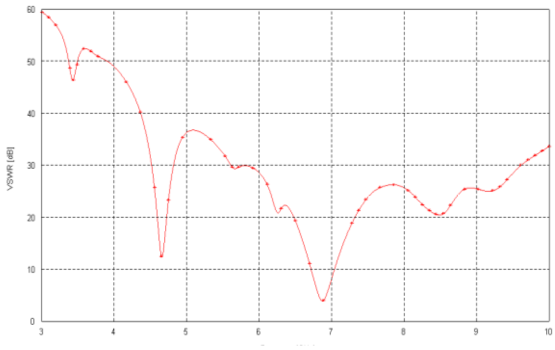

Fig. 9: VSWR graph of a square microstrip antenna with truncated corners

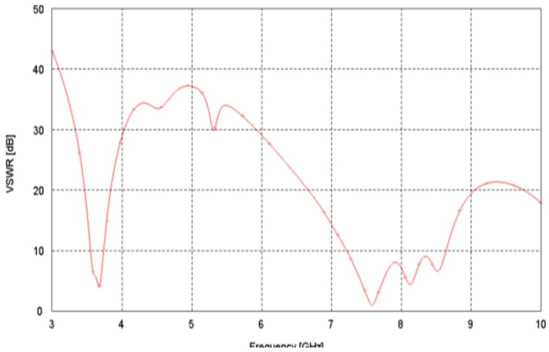

Fig. 10: VSWR graph of an ANN-based square microstrip antenna

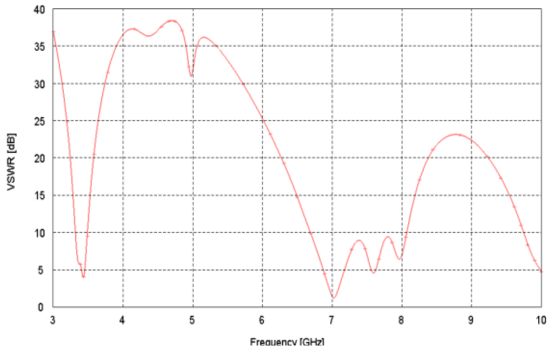

Fig. 11: VSWR graph of a PSO-based square microstrip antenna

Figs. 12 and 13 show the comparison charts of the measured parameters. For bandwidth enhancement in RADAR, circular structure is preferred over the square patch. Fig. 14 shows the S11 values for antennas with sixteen conductive vias circular patch antenna and Fig. 15 for antennas with sixteen conductive vias. Fig. 7 shows the graphs displaying the values of S11 obtained by particle swarm optimization and genetic algorithm. Here the circular patch antenna is optimized using PSO and genetic algorithm (GA) and the latter is showing better results as shown in Fig. 15.

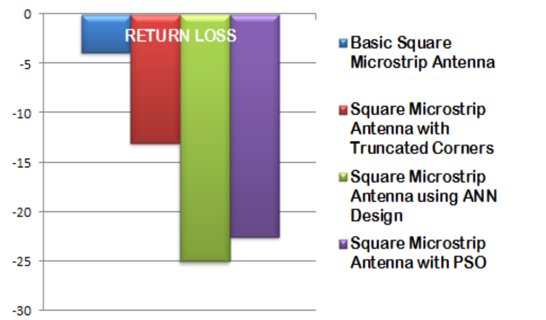

Fig. 12: Comparison of return loss for square patch antenna

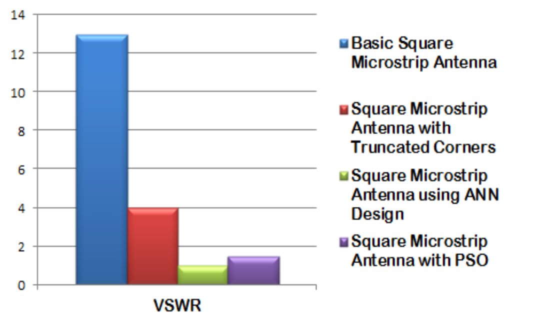

Fig. 13: Comparison of VSWR for square patch antenna

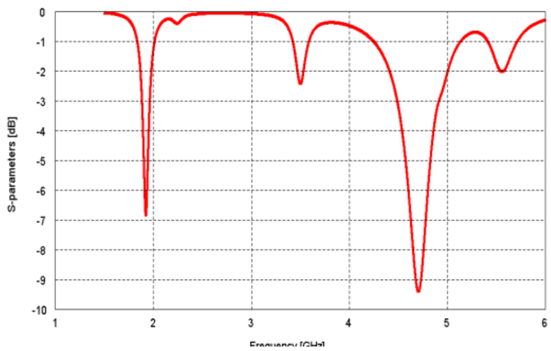

Fig. 14: S11 value for circular patch antenna for N = 16

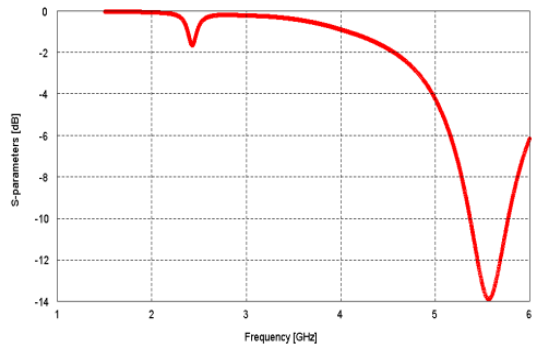

Fig. 15: S11 value for PSO optimized patch antenna

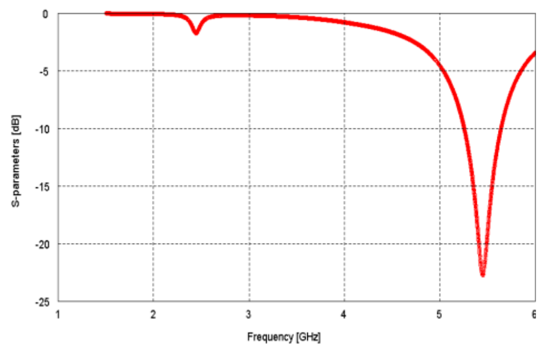

Fig. 16: S11 value for GA optimized patch antenna

For N = 16, the inference is that the value of S11 is -9.3dB and the impedance bandwidth are found to be 24.4%. Lower the value of S11, better is the impedance matching property of the antenna. So, we can finally see that the best S11 value and the best impedance bandwidth is obtained when the number of conductive vias, N = 16. For GA, the inference is that the value of S11 is -23dB and the impedance bandwidth are found to be 46.2%. Lower the value of S11, better is the impedance matching property of the antenna. So, we can finally see that the best S11 value and the best impedance bandwidth is obtained when the number of conductive vias, N = 16. For GA, the inference is that the value of S11 is -23dB and the impedance bandwidth are found to be 46.2%. Lower the value of S11, better is the impedance matching property of the antenna. So, we can finally see that the best S11 value is obtained for the antenna optimized using the GA method.

4. Conclusion

A simple single feed square microstrip antenna is first designed and analyzed. The main parameters analyzed are S11 and VSWR. But the resulting graphs display that the values obtained are not very satisfactory. As a result, the corners of the single feed square shaped microstrip patch antenna are pierced, and the results are analyzed. The graphs show much more improved values for the parameters S11 and VSWR. So, from this, we can conclude that truncation of the corners of the patch of a microstrip antenna leads to the improvement of parameters. This helps us to make use of the microstrip antenna for more useful applications like radar. Then, neural network based design is introduced, for designing the microstrip antenna. An important division of ANNs, the multilayer perceptron (MLP) is used for analysing and Levenberg-Marquardt (LM) algorithm is adopted to train the MLPs for obtaining high-precision synthesis models. Finally, the square microstrip antenna is designed with the help of the physical parameters obtained via equations in ANN. The designed square antenna is found to show a considerable improvement in S11 and VSWR values, and hence, can be used in various modern applications.

Also, the designed antennas are proved to radiate in the C-band, which covers frequencies in the range 5-8GHz, applicable in most of the modern radars. The results of circular microstrip patch antenna are found to show that as the number of vias N increases, the capacitance decreases and as a result, the resonant frequency increases. The reflection coefficient of the antenna - without using vias, is found to be very high and this leads to poor impedance matching. Another observed result is that when the number of N is chosen properly, a broadband antenna is obtained. N mainly depends on - thickness of the substrate and the radius of the vias. The microstrip patch antenna has several applications, some of them being: mobile and satellite communication, global positioning system (GPS), radio frequency identification, Worldwide Interoperability for Microwave Access (WiMax), radar applications, telemedicine applications, etc. Because of its wide bandwidth, circular patch antennas are widely preferred for RADAR applications.

REFERENCES:

[1] M. Villano, F. Colone and P. Lombardo. 2013. Antenna array for passive radar: configuration design and adaptive approaches to disturbance cancellation, *Int. J. Antennas & Propagation*, Article ID 920639. http://dx.doi.org/10.1155/2013/920639.

[2] I. Singh, V.S. Tripathi and I. Singh. 2011. Micro strip patch antenna and its applications: a survey, *Int. J. Comp. Tech. Applications*., 2(5), 1595-1599.

[3] V.R. Komanduri, D.R. Jackson, J.T. Williams and R.A. Mehrotra. 2013. A general method for designing reduced surface wave microstrip antennas, *IEEE Trans. Antennas and Propagation*, 61(6), 2887-2894. https://doi.org/10 1109/TAP.2013.2254441.

[4] S.K. Podilchak, M. Caillet, D. Lee, M. Yahia and M. Antar. 2013. A compact circularly polarized antenna using an array of folded-shorted patches, *IEEE Trans. Antennas and Propagation*, 61(9), 4861-4867. http://dx.doi:10.1109 /TAP.2013.2254441.

[5] A. Sharma and G. Singh. 2009. Rectangular microstrip patch antenna design at THz frequency for short distance wireless communication systems, *J. Infrared, Millimetre*

and Terahertz Waves, 30(1), 1-7. http://dx.doi:10.1007/s10762-008-9416-z.

[6] S.S. Karimabadi, Y. Mohsenzadeh, A.R. Attari and S.M. Moghadasi. 2008. Bandwidth enhancement of single-feed circularly polarized equilateral triangular microstrip antenna, *Progress in Electromagnetics Research Symp.*, Hangzhou, China.

[7] E.R. Brinhole, J.F.Z. Destro, A.A.C. de Freitas and N.P. de Alcantara Jr. 2005. Determination of resonant frequencies of triangular and rectangular microstrip antennas, using artificial neural networks, *Progress in Electromagnetics Research Symp.*, https://doi.org/10.2529/PIERS041210091305.

[8] S.L.S. Yang, K.F. Lee and A.A. Kishk. 2008. Design and study of wideband single feed circularly polarized microstrip antennas, *Progress in Electromagnetics Research Symp.*, 80, 45-61. https://doi.org/10.2528/PIER07110604.

[9] P. Bengal and A.K. Gautam. 2011. Square microstrip antenna for circular polarization operation, *Int. J. Computer Applications*, 36(4), 0975-8887.

[10] M. Ramirez and J. Parron. 2011. Circularly-polarized stacked annular-ring microstrip antenna, *Progress in Electromagnetics Research Letter*s, 23, 99-107. https://doi.org/10.2528/PIERL11032203.

[11] A.A. Heidari and A. Dadgarnia. 2011. Design and optimization of a circularly polarized microstrip antenna for GPS applications using ANFIS and GA, *Proc. XXXth URSI General Assembly and Scientific Symp.*,1-4. http://dx.doi:10.1109/URSIGASS.2011.6050470.

[12] Z.J. Tamboli and P.B. Nikam. 2013. Study of multilayer perceptron neural network for antenna characteristics analysis, *Int. J. Adv. Research in Computer Sci. and Software Engg.*, 3(8), 200-203.

[13] N. Turker, F. Gunes and T. Yildirim. 2004. *Artificial Neural Design of Microstrip Antennas*, Yildiz Technical University, Istanbul, Turkey.

[14] J.S. Thomas, J.S. Thomas, T.M. Neebha and M. Nesasudha. 2014. Improvement of microstrip patch antenna parameters for wireless communication, *Proc. Int. Conf. Electronics & Communication Systems*, http://dx.doi: 10.1109/ECS.2014.6892550.

[15] *MATLAB Neural Network Toolbox*, 2011.

[16] M.H. Beale, M.T. Hagan and H.B. Demuth. 2013. *Neural Network Toolbox* - User's Guide.

[17] D.M. Pozar. 2011. Microstrip antennas, *IEEE Proc.*, 80(1), 79-91. https://doi.org/10.1109/5.119568

[18] C.A. Balanis and C.R. Cockrell. 1971. Analysis and design of antennas for air traffic collision avoidance systems, *IEEE Trans. Aero. & Electronic Systems*, 7(5), 960-967. https://doi.org/10.1109/TAES.1971.310337.

[19] T.M. Neebha and M. Nesasudha. 2016. Design and analysis of advanced microstrip patch antenna for endoscopic capsules, *Microwave and Optical Tech. Letter*s, 58(7). http://dx.doi.org/10.1002/mop.29904.

[20] P. Kala, R. Saxena, M. Kumar, A. Kumar and R. Pant. 2013. Design of rectangular patch antenna using MLP artificial neural network, *J. Global Research in Computer Sci.*, 3(5), 11-14.