**Microstrip Antenna Optimization using Evolutionary Algorithms**

**Kalpa Ranjan Behera1, Surender Reddy Salkuti2,\*, Tapas Kumar Patra3, Balaram Sabat4**

1,2Department of Railroad and Electrical Engineering, Woosong University, Daejeon, Republic of Korea

3,4Department of Instrumentation and Electronics Engineering, CET Bhubaneswar, India

|  |  |  |
| --- | --- | --- |
| **Article Info** |  | **ABSTRACT** |
| ***Article history:***  Received Jan. 02, 2021  Revised XXXXX  Accepted XXXXX |  | Different strncture of microstrip antenna optimization using different algorithms are the important field of wireless communications. Rectangular microstrip antenna, in­ ve1ted E-shaped antenna, tullip shaped antenna are some examples of microstrip antennas. The antenna dimensions are optimized by different algorithms. The operating frequencies for different antenna structures are depend on antenna dimensions. The frequency of operation is (3-lS) GHz for rectangular antenna, IMT-2000 for inve1ted E-shaped antenna, (8-12) GHz for tullip shaped antenna, 2.16 GHz for miniaturized antenna structure. The dimensions of microstrip antennas are modified to get minimum reflection coefficient maximum gain and bandwidth. The dimensions are modified using different algorithms such as evolutionary algorithm, particle swarm optimization, aitificial neural network and genetic algorithms. |
| ***Keywords:***  Microstrip antenna  E-shape microstrip antenna Tulip shape antenna Differential evolution  Particle swarm optimization Artificial neural network Genetic algorithm |
| *This is an open access article under the* [*CC BY-SA*](https://creativecommons.org/licenses/by-sa/4.0/) *license.* |
| ***Corresponding Author:***  Surender Reddy Salkuti,  Department of Railroad and Electrical Engineering,  17-2, Woosong University, Jayang-dong, Dong-gu, Daejeon-34606, Republic of Korea.  Email: surender@wsu.ac.kr | | |

**NOMENCLATURE**

Effective permitivity of substrate

Resonant frequency

Speed of light

Effective length

Effective permitivity of substrate

Fitness function

Desired resonant frequency

Optimized resonant frequency

Desired returnloss

Returnloss

, Biasing constants

Obtained cutoff frequency

Target cutoff frequency

Obtained bandwidth

Target bandwidth

Velocity of agent i iteration k

Weight function

Weight factor

Random number between 0 and 1

Current position of agent i and iteration k

Local best of agent i

Global best

Total sampling points

Sampling frequency

Error found in one frequency

1. **INTRODUCTION**

Wireless communication is broadly used in today’s communication technology. Antennas are integral part of wireless communication. Microstrip antennas are popular due to its small size, lightweight and efficiency. So it's used broadly in mobile phones, aeroplanes, satellites, 5G communication etc [1]. The antenna output such as bandwidth, return loss, resonant frequency are depend on antenna structure. So antenna dimensions are chosen carefully to get required output. To choose right dimension, it's required to optimize the antenna. Optimization is processed by applying different algorithms [2] [3]. The algorithms generate different solution for different dimensions and different structure. The defective element recognition can takes place using different algorithms [4]. Differential evolution is an algorithm that use mutation and recombination to generate solution. First population is go through mutation. So that new solution generated in this process. After mutation crossover is take place between the solution and new solution generates. This process continues till desire solution. Resonant frequency is optimized for rectangular microstrip antennas using evolutionary algorithm for frequency band 3 GHz to 18 GHz [5]. Particle swarm optimization inspired by birds flocking and fish schooling. Each bird or particle represent as solution. Each particle search for solution in its locality. The best solution found by each particle is replaced by previous solution. Likewise each group has a best solution which replace by next best solution. The solution obtained at last by group is the best solution [6]. Bandwidth is improved for E-shape microstrip antenna by optimizing antenna parameters using particle swarm optimization [7]. Artificial neural network is inspired from neurons of human brain. Like human brains having neuron cells that process information from input to output, ANN has neurons that process information based on some weights. The ANN use past experience in back propagation algorithm and come out with perfect results. Dimension optimization is another technique for modified tulip shaped microstrip antenna using artificial neural network in X/Ku band [8].

Genetic algorithm is inspired from Charles Darwin's theory natural selection. natural selection is based on fittest individual. The fitness function give the fitness value. Crossover takes place between the pair having best fitness value. The obtained offspring mutate some percentage and it's fitness value evaluated. The process takes place till the best solution. Using genetic algorithm for rectangular antenna is an helpful technique to miniaturize antenna shape [9] [10]. The antenna parameters such as return loss, gain, bandwidth is depend on antenna dimensions (length, width, height), substrate type, ground plane dimension etc. Radiation pattern and impedance are also varies with antenna dimensions and antenna type. A microstrip antenna is designed using Boolean particle swarm optimization and method of moments [11]. The geometry of microstrip antenna depend on cross polarization, return loss and bore sight directions. A circularly polarized stacked microstrip antenna has optimized feeding techniques. A c-type feeding technique is used in the antenna structure [12]. The optimization technique applied to feed along with return loss and bandwidth. A quasi planar surface planar short horn antenna attached to the microstrip antenna for higher gain. The antenna is used in wideband circularly polarized and higher gain applications. A buried microstrip antenna optimized using genetic algorithm and finite deference time domain. The antenna optimized for maximum soil moisture sensing. The variation in performance due to soil moisture is minimized by designing. The communication is performed between buried antenna and receiver antenna [13]. Complementary particle swarm antenna is designed using particle swarm optimization technique. The particle swarm optimization technique is used to place parasitic sub patch in proper place to get minimum reflection coefficient. Substrate optimization technique is used optimize antenna performance. Reciprocity theorem and integral equations are used as optimization tools in this process. Bandwidth and radiations are optimized for dipole and slot antenna. the optimized value is found out by varying substrate height and permittivity of substrate [14]. Two optimization techniques are used to optimize rectangular microstrip antenna. One is global optimizer called central force optimization and another is local optimization called Nelder-Mead optimization. the combination of global optimization followed by local optimization is called hybrid central force optimization-Nelder-Mead approach. The optimization process perform better than other optimization process on given benchmark functions [15].

In the next section different types of microstrip antennas are described along with characteristic properties [16]. The charactrictics varies with antenna dimensions, substrate types [17]. Optimized gain, bandwidth, reflection coefficient is found out by appling optimization techniques. Rectangular, tulip, inverted-E shaped antennas are taken for optimization. Optimization process use algorithms such as Differential Evolution, Genetic algorithm, Particle swarm optimization and artificial neural network in the subsections of 2nd section [18]. At the conclusion part we get, the optimized result may vary according to the algorithms applied to it.

## Types of Optimization for Microstrip Antena

**2.1 Differential Evolution used in rectangular microstrip antenna**

A rectangular microstrip antenna with insert feed line have been chosen for optimization and it is shown in figure 1. The length, width and feed position are selected as antenna parameters. Return loss is required parameter to optimize by adjusting the values of length, width and feed position. Rectangular antenna chosen due to its simple antenna parameters. The resonant frequency is calculated for rectangular microstrip antenna by given formula. The effective length of antenna is usually longer than actual physical length. It is due to fringing effect. Effective length is calculated by its formula. Effective permittivity () is a function of of substrate permitivity (). Substrate Permitivity depends on type of substrate in use. For example substrate permitivity for FR4 substrate is 4.4 [5] [19].

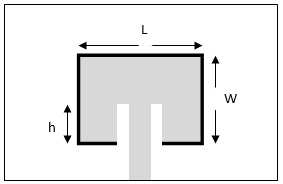


Figure 1: Rectangular microstrip antenna.

Resonant frequency () is given by,

A fitness function is a type of objective function that use to compare between design solution and desired solution. Fitness function gives a real number value that helps to improve our design. Fitness function minimization is used in optimization process. For maximization purpose, we use negative sign and vice versa.

Fitness function called parameter estimation in statistics. It is use to get perfect pair of population of size 1X3. In (1X3) 1 is represent number of iteration and 3 is represent antenna parameter such as length, width and feed position. A random population is generated for length, width and feed position. In nest iteration population is updated using equation given below.

is the random generated population. The population is mutate and crossover to get new population in differential evolution algorithm . Best fitness value is compared with the desired value and antenna parameter is updated for next generation population. The process continues till desired solution found. The solution parameters are fitted with zeeland IE3D software and return loss found out. The return loss is use in fitness function to impeove antenna parameters.

**2.2. PSO used in inverted E shaped patch antenna**

The inverted E shaped microstrip antenna fed with probe is optimized for bandwidth maximization. The independent antenna parameters are length, width, slot length and slot width. The aim is to maximize antenna bandwidth by varying antenna parameters and making centre frequency constant at IMT-2000 band.

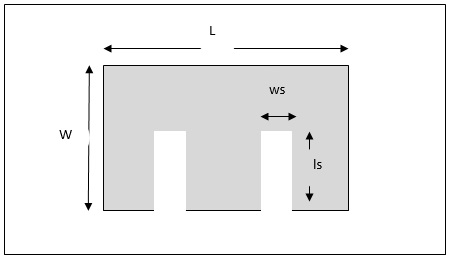


Figure 2. Inverted E-shape microstrip antenna.

To get curve fit equation, bandwidth required by varying one independent variable and making other independent variable constant. 54 observations have been found out by varying antenna length and making antenna width, slot length and slot width constant. Same procedure having applied for antenna width, slot length and slot width. Four tables are formed by varying four independent variable separately. For each table graphmatica forms different equations. The graphmatica is curve fitting software to generate curve fitting equations.

The fitness function is generated using root mean square error. The fitness function for our antenna is given below. M and N are biasing constants to control overall fitness. The PSO optimized using MATLAB code.

A number of random population generated in the search space called agents (particles). Each particle represents a point in the search space. Each particle modify its position by using information about current position, velocity, local best and global best. The best coordinate (fitness) found by each particle is called local best. The best coordinate found by the group of particles is called global best. The distance between current position and local best is called pbest and distance between current position and global best is called gbest [20] [21].

The solution found after termination of the process is the optimized solution. The solution found by PSO method is better than the conventional method.

* 1. **Artificial neural network used in tulip shaped microtrip antenna**

Modified leaf microstrip antenna has many more advantages over simple microstrip antenna, such as higher radiation, multi band operating mode, wider band width and small size. Tulip microstrip antenna is the combination of many modified leaf microstrip antennas. Here we need to operate tulip microstrip antenna in X/Ku band. X band is in the range of 8GHz to 12GHz and Ku band is in the range of 12GHz to 18GHz. The antenna is fed with coaxial probe [22]. The parameters for microstrip antenna are D, R1, R2 and W2. The proposed antenna is simulated through HFSS simulation software. The output return loss and resonant frequency for X/Ku band found out.

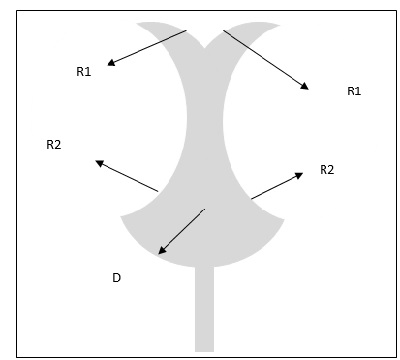


Figure 3. Tullip shaped microstrip antenna.

By the help of artificial neural network a better value for return loss and resonant frequency is found out. Back propagation is a method used to optimize the artificial neural network. It is a multi layer perceptron network. Four dependent variables (, , , ) are the four input layer of neurons and four independent variables (, , , ) are four output layer of neuron [23] [24]. Number of hidden layers taken is 12 and number of epochs are 2000. The ANN model is trained over different structures. It is observed the ANN trained model performs better with its past experience.

* 1. **Microstrip antenna miniaturization using genetic algorithm**

Microstrip antenna size is decreasing due to rapid reduction in the size of communication devices. The rectangular microstrip patch is divided into small uniform rectangular cells. Each cell is either conducing material or nonconducting material. The cells are arranged in such a way that it gives required output. The resonance frequency shift is the desire output for this optimization process [25].

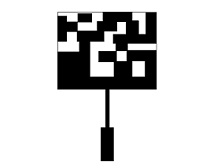


Fig. 4. Miniaturized microstrip antenna.

A metal patch is divided into number of square patches. A string of 20 random binary number is chosen to get population in the process of genetic algorithm optimization [26]. According to string the binary one is represented with metal conducting materials and binary 0 replaced with nonconducting material on the antenna surface. The output for resonant frequency and return loss is calculated with the help of a software CST [27] [28]. The cost function is calculated on the result obtained from CST with the help of MATLAB.

A new generation of binary string is required to improve the result. So a new generation is formed by random single point crossover. The offspring obtained from crossover is mutated. Maximum 5 bits are mutated in this process [29, 30]. The resonant frequency and return loss is found for new generation and cost function is evaluated. The process crossover, mutation, fitness function evaluation is continues till the desired result found. The binary numbers contained in final generation is our desire output. The binary numbers applied to the antenna structure to generate optimized solution. The frequency shifts from 4.9 to 2.16 GHz with miniaturization shape of rectangular microstrip antenna [31]. Optimized antenna could be dual polarized and broadband. Different optimization process gives different optimized solutions that may desired or not.

1. **CONCLUSION**

The optimized value of microstip antennas are efficient irrespective of structures. The return loss obtained in this optimization process is always better than non-optimize one. The optimized value of different algorithms are comparable. The result may vary and could be better for any other optimization algorithms. Optimization never limits the shape of antenna dimensions. Optimization modify its dimension to get better results. The application of differential evolution, particle swarm algorithm, genetic algorithm and artificial neural network to microstrip antenna is discussed in the section. Different microstrip antennas such as rectangular microstrip antenna, tulip antenna, inverted-E antenna are optimized using these algorithms.

Area for future research includes application of machine learning algorithms to the antenna design process. Some nature inspired optimization algorithms could be applied to the antennas to get optimized antenna characteristics. The algorithms could applied to thedifferent structures of microstrip antenna such as slot antenna, antenna array, parasitic antennas etc.

**ACKNOWLEDGEMENTS**

This research work has been carried out based on the support of “Woosong University’s Academic Research Funding - (2020-2021)”.

**REFERENCES**

|  |  |
| --- | --- |
| [1] | H. M. a. Q. N. Marhoon, “Simulation and optimization of tuneable microstrip patch antenna for fifth-generation applications based on graphene,” *International Journal of Electrical and Computer Engineering (IJECE),* vol. 10, no. 5, pp. 5274--5287, 2020. |
| [2] | A. a. B. A. a. B. A. a. B. A. Zaidi, “Design and Optimization of a High Gain Multiband Patch Antenna for Millimeter Wave Applications.,” *International Journal of Electrical \& Computer Engineering (2088-8708),* vol. 8, 2018. |
| [3] | O. A. a. O. M. O. a. O. M. A. Ojo, “Optimetric analysis of 1x4 array of circular microwave patch antennas for mammographic applications using adaptive gradient descent algorithm,” *International Journal of Electrical and Computer Engineering (IJECE),* vol. 9, no. 6, pp. 1-7, 2017. |
| [4] | S. U. a. R. M. a. A.-B. M. a. K. A. E. K. a. S. A. Khan, “Diagnosis of faulty elements in array antenna using nature inspired cuckoo search algorithm,” *International Journal of Electrical and Computer Engineering,* vol. 8, no. 3, p. 1870, 2018. |
| [5] | P. M. U. S. B. G. S. M. M. Gangopadhyaya, “Design optimization of microstrip fed rectangular microstrip antenna using differential evolution algorithm,” *IEEE 2nd International Conference on Recent Trends in Information Systems (ReTIS),* pp. 49-52, 2015. |
| [6] | A. a. O. W. Hamid, “Hexa-band MIMO CPW Bow-tie Aperture Antenna Using Particle Swarm Optimization,” *International Journal of Electrical and Computer Engineering,* vol. 8, no. 5, p. 3118, 2018. |
| [7] | B. C. c. P. I. E. R. v. 7. p. 3. 2. B.K. Ang, “A wideband e-shaped microstrip patch antenna for 5-6 ghz wireless communications,” *Progress In Electromagnetics Research,* vol. 75, pp. 397-407, 2007. |
| [8] | L. S. U. Ozkaya, “Dimension optimization of microstrip patch antenna in x/ku band via artificial neural network,” *Procedia-Social and Behavioral Science,* pp. 2520-2525, 2015. |
| [9] | J. A. P. D. U. e. a. J. Ayasinghe, “Genetic algorithm optimization of a high-directivity microstrip patch antenna having a rectangular profile,” *Radioengineering,* vol. 22, 2013. |
| [10] | J. A. D. U. J.W. Jayasinghe, “A simple design of multi band microstrip patch antennas robust to fabrication tolerances for gsm, umts, lte, and bluetooth applications by using genetic algorithm optimization,” *Progress in Electromagnetics Research,* vol. 27, pp. 255-269, 2012. |
| [11] | A. M. M. S. F. Afshinmanesh, “Design of a singlefeed dual-band dual-polarized printed microstrip antenna using a Boolean particle swarm optimization,” *IEEE Transactions on Antennas and Propagation,* pp. 1845-1852, 2008. |
| [12] | A. V. e. a. K.P. Esselle, “Wideband high-gain circularly polarized stacked microstrip antennas with an optimized c-type feed and a short horn,” *IEEE transactions on antennas and propagation,* vol. 56, no. 2, pp. 578-581, 2008. |
| [13] | C. F. Y. C. B. L. P. Soontornpipit, “Optimization of a buried microstrip antenna for simultaneous communication and sensing of soil moisture,” *IEEE transactions on antennas and propagation,* vol. 54, no. 3, pp. 797-800, 2006. |
| [14] | P. K. D. R. N.G. Alexopoulos, “Substrate optimization for integrated circuit antennas,” *IEEE Transactions on Microwave Theory and Techniques,* vol. 31, no. 7, pp. 550-557, 1983. |
| [15] | K. Mahmoud, “Central force optimization: Nelder-mead hybrid algorithm for rectangular microstrip antenna design,” *Electromagnetics,* vol. 31, no. 8, pp. 578-592, 2011. |
| [16] | C. Balanis, Antenna theory: analysis and design, John wiley & sons, 2016.. |
| [17] | K. R. G. Kumar, Broadband microstrip antennas, Artech house, 2003. |
| [18] | J. R. B. G. A. Deb, “Performance comparison of differential evolution, particle swarm optimization and genetic algorithm in the design of circularly polarized microstrip antennas,” *IEEE transactions on antennas and propagation,* vol. 62, no. 8, pp. 2920-2928, 2014. |
| [19] | S. P. O. B. S. D. C. V. S. P. P. K. B. S.V. Gollapudi, “Bacterial foraging optimization technique to calculate resonant frequency of rectangular microstrip antenna,” *International Journal of RF and Microwave Co,* vol. 18, no. 4, pp. 383-388, 2008. |
| [20] | T. B. A.A. Minasian, “Particle swarm optimization of microstrip antennas for wireless communication systems,” *IEEE Transactions on Antennas and Propagation,* pp. 6214-6217, 2013. |
| [21] | N. M. T. C. T. M. M. M.T. Islam, “Optimization of microstrip patch antenna using particle swarm optimization with curve fitting,” *International Conference on Electrical Engineering and Informatics,* pp. 711-714, 2009. |
| [22] | M. H. a. R. S. K. A. a. S. M. A. M. a. O. M. A. Misran, “A systematic optimization procedure of antenna miniaturization for efficient wireless energy transfer,” *International Journal of Electrical and Computer Engineering,* vol. 9, no. 4, p. 3159, 2019. |
| [23] | S. M. M. A. L. A. O. Ozgun, “Design of dualfrequency probe-fed microstrip antennas with genetic optimization algorithm,” *IEEE Transactions on Antennas and Propagation,* vol. 51, no. 8, pp. 1947-1954, 2003. |
| [24] | A. E. H. M. B. N. T. a. T. E. M. Lamsalli, “Genetic algorithm optimization for microstrip patch antenna miniaturization,” *Progress In Electromagnetics Research,* pp. 113-120, 2016. |
| [25] | S. S. A. Singh, “Design and optimization of a modified sierpinski fractal antenna for broadband applications,” *Applied Soft Computing,* vol. 38, pp. 843-850, 2016. |
| [26] | A.A. Al-Azza, “Spider monkey optimization: A novel technique for antenna optimization,” *IEEE Antennas and Wireless Propagation Letters,* vol. 15, pp. 1016-1019, 2015. |
| [27] | V. V. M. S. R.C. Mahajan, “Performance prediction of electromagnetic band gap structure for microstrip antenna using fdtd-pbc unit cell analysis and taguchi’s multi-objective optimization method,” *Microelectronic Engineering,* vol. 219, 2020. |
| [28] | N. K. F.M. Monavar, “Bandwidth enhancement of microstrip patch antenna using jerusalem cross-shaped frequency selective surfaces by invasive weed optimization approach,” *Progress In Electromagnetics Research,* vol. 121, pp. 103-120, 2011. |
| [29] | A. B. A. B. A. B. A. Zaidi, “Design and optimization of an inset fed circular microstrip patch antenna using dgs structure for applications in the millimeter wave band,” *IEEE International Conference on Wireless Networks and Mobile Communications, 2016, pp. 99–103.,* pp. 99-103, 2016. |
| [30] | E. W. M. B. E. Hassan, “Topology optimization of metallic antennas,” *IEEE transactions on antennas and propagation,* vol. 62, no. 5, pp. 2488-2500, 2014. |
| [31] | R. a. A. H. Kavitha, “An Analytical Approach for Design of Microstrip Patch (MsP).,” *International Journal of Electrical \& Computer Engineering (2088-8708),* vol. 8, 2018. |