IAES International Journal of Artificial Intelligence (IJ-AI)
Vol. 11, No. 3, September 2022, pp. 836~842
ISSN: 2252-8938, DOI: 10.11591/ijai.v11.i3.pp836-842

Microstrip antenna optimization using evolutionary algorithms

Kalpa Ranjan Behera, Surender Reddy Salkuti
Department of Railroad and Electrical Engineering, Woosong University, Daejeon, Republic of Korea

Article Info

Article history:

Received Aug 5, 2021
Revised May 22, 2022
Accepted May 31, 2022

Keywords:

Artificial neural network
Differential evolution
E-shape microstrip antenna
Genetic algorithm
Microstrip antenna
Particle swarm optimization
Tulip shape antenna

ABSTRACT

Different structures of microstrip antenna optimization using different algorithms are the important field of wireless communications. Rectangular microstrip antenna, inverted E-shaped antenna, tulip shaped antenna are some examples of microstrip antennas. The antenna dimensions are optimized by different algorithms. The operating frequencies for different antenna structures depend on antenna dimensions. The frequency of operation is 3-lS GHz for rectangular antenna, IMT-2000 for invelted E-shaped antenna, 8 to 12 GHz for tulip 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 (PSO), artificial neural network (ANN), and genetic algorithms (GA).

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

ε_{reff}	Effective permittivity of substrate	$f_{c,target}$	Target cutoff frequency
f_r	Resonant frequency	BW	Obtained bandwidth
c	Speed of light	BW_{target}	Target bandwidth
L_{eff}	Effective length	V_i^k	Velocity of agent i iteration k
ε_{reff}	Effective permittivity of the substrate	ω	Weight function
F	Fitness function	c	Weight factor
f_0	Desired resonant frequency	$rand$	Random number between 0 and 1
F_0	Optimized resonant frequency	s_i^k	Current position of agent i and iteration k
L_R	Desired return loss	$pbest_i$	Local best of agent i
L_0	Return loss	$gbest$	Global best
M, N	Biasing constants	N	Total sampling points
f_c	Obtained cutoff frequency	f_i	Sampling frequency
		$Q(f_i)$	Error found in one frequency

1. INTRODUCTION

Wireless communication is broadly used in today's communication technology. Antennas are an integral part of wireless communication. Microstrip antennas are popular due to their small size, lightweight, and efficiency. So it's used broadly in mobile phones, airplanes, satellites, and 5G communicatio [1]. The antenna output such as bandwidth, return loss, the resonant frequency depends on antenna structure. So antenna dimensions are chosen carefully to get the required output. To choose the right dimension, it's required to optimize the antenna. Optimization is processed by applying different algorithms [2], [3]. The algorithms generate different solutions for different dimensions and different structures. The defective element recognition can take place using different algorithms [4]. Differential evolution is an algorithm that uses mutation and recombination to generate a solution. The first population is go through mutation. So that a new solution is generated in this process. After mutation crossover is take place between the solution and the new solution generated. This process continues till the desired solution. The resonant frequency is optimized for rectangular microstrip antennas using an evolutionary algorithm for frequency band 3 to 18 GHz [5]. Particle swarm optimization (PSO) inspired by birds flocking and fish schooling. Each bird or particle represents the solution. Each particle search for a solution in its locality. The best solution found by each particle is replaced by the previous solution. Likewise, each group has the best solution which replaces by the next best solution. The solution obtained at last by the group is the best solution [6]. Bandwidth is improved for E-shape microstrip antenna by optimizing antenna parameters using PSO [7]. The artificial neural network (ANN) is inspired by neurons of the 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 uses experience in the backpropagation algorithm and comes out with perfect results. Dimension optimization is another technique for modified tulip-shaped microstrip antenna using an ANN in the X/Ku band [8].

The genetic algorithm (GA) is inspired by Charles Darwin's theory of natural selection. natural selection is based on the fittest individual. The fitness function gives the fitness value. A crossover takes place between the pair having the best fitness value. The obtained offspring mutate some percentage and its fitness value is evaluated. The process takes place till the best solution. Using a GA for the rectangular antenna is a helpful technique to miniaturize antenna shape [9], [10]. The antenna parameters such as return loss, gain, bandwidth depend on antenna dimensions (length, width, height), substrate type, and ground plane dimension. Radiation patterns and impedance also vary with antenna dimensions and antenna type. A microstrip antenna is designed using boolean PSO and the method of moments [11]. The geometry of the microstrip antenna depends 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 is applied to feed along with return loss and bandwidth. A quasi planar surface planar short horn antenna is 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 GA and finite difference time domain. The antenna is optimized for maximum soil moisture sensing. The variation in performance due to soil moisture is minimized by design. The communication is performed between the buried antenna and receiver antenna [13]. A complementary particle swarm antenna is designed using the PSO technique. The PSO technique is used to place the parasitic sub-patch in the proper place to get a minimum reflection coefficient. The substrate optimization technique is used to 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 a 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 the hybrid central force optimization-Nelder-Mead approach. The optimization process performs better than another optimization process on given benchmark functions [15].

In the next section, different types of microstrip antennas are described along with characteristic properties [16]. The characteristics vary with antenna dimensions, substrate types [17]. Optimized gain, bandwidth, the reflection coefficient is found out by applying optimization techniques. Rectangular, tulip, inverted-E shaped antennas are taken for optimization. Optimization process use algorithms such as: i) differential evolution, ii) GA, iii) PSO, and iv) ANN 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.

2. TYPES OF OPTIMIZATION FOR MICROSTRIP ANTENA

2.1. Differential evolution used in rectangular microstrip antenna

A rectangular microstrip antenna with an insert feed line has 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 a required parameter to optimize by adjusting the values of length, width, and feed position. The rectangular antenna is chosen due to its simple antenna parameters. The resonant frequency is calculated for rectangular microstrip antenna by the given formula. The effective length of the antenna is usually longer than the actual physical length. It is due to the fringing effect. Effective length is calculated by its formula. Effective permittivity (ε_{reff}) is a function of substrate permittivity (ε_r). Substrate permittivity depends on the type of substrate in use. For example substrate permittivity ε_{eff} for FR4 substrate is 4.4 [5], [19].

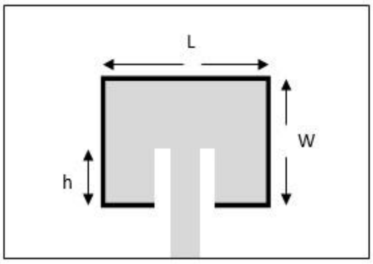

Figure 1. Rectangular microstrip antenna

Resonant frequency (f_r) is given by

$$f_r = \frac{c}{2L_{eff}\sqrt{\varepsilon_{reff}}} \quad (1)$$

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

$$F = |f_0 - F_0| + |L_R - L_0| \quad (2)$$

Fitness function called parameter estimation in statistics. It is used to get the perfect pair of the population of size 1×3. In (1×3) 1 is represent a number of iteration and 3 represents antenna parameters 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 (3).

$$x_{i,G}^{j} = x_{min}^{j} + rand(0,1) \times \left(x_{max}^{j} - x_{min}^{j}\right) \quad (3)$$

x is the randomly generated population. The population is mutated and crossover to get a new population in the differential evolution algorithm. The best fitness value is compared with the desired value and the antenna parameter is updated for the next-generation population. The process continues till the desired solution is found. The solution parameters are fitted with Zeeland IE3D software and return loss is found out. The return loss is used in the fitness function to improve antenna parameters.

2.2. Inverted E-shaped patch antenna

The inverted E-shaped microstrip antenna fed with the probe is optimized for bandwidth maximization and it is depicted in Figure 2. 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 center frequency constant at the IMT-2000 band.

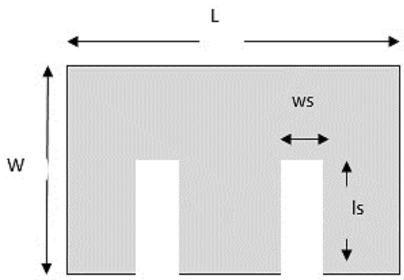

Figure 2. Inverted E-shape microstrip antenna

To get the curve fit equation, the bandwidth is required by varying one independent variable and making other independent variables constant. 54 observations have been found out by varying antenna length and making antenna width, slot length, and slot width constant. The same procedure has been applied for antenna width, slot length, and slot width. Four tables are formed by varying four independent variables 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 is optimized using MATLAB code.

$$F(x) = \sqrt{M(f_c - f_{c,target})^2 + N(BW - BW_{target})^2} \tag{4}$$

A number of random populations generated in the search space are called agents particles. Each particle represents a point in the search space. Each particle modifies 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 the current position and local best is called pbest and the distance between the current position and global best is called gbest [20], [21]. The solution found after the termination of the process is the optimized solution. The solution found by PSO method is better than the conventional method.

$$V_i^{k+1} = \omega V_i^k + c_1 rand_1 \left(pbest_i - s_i^k\right) + c_2 rand_2 \left(gbest - s_i^k\right) \tag{5}$$

2.2.1. Artificial neural network used in tulip-shaped microstrip antenna

Modified leaf microstrip antenna has many more advantages over simple microstrip antenna, such as higher radiation, multi-band operating mode, wider bandwidth, and small size. Tulip microstrip antenna is the combination of many modified leaf microstrip antennas and it is depicted in Figure 3. Here we need to operate a tulip microstrip antenna in X/Ku band. X band is in the range of 8 to 12 GHz and Ku band is in the range of 12 to 18 GHz. The antenna is fed with a coaxial probe [22]. The parameters for microstrip antenna are D, R1, R2, and W2. The proposed antenna is simulated through high-frequency structure simulator (HFSS) simulation software. The output return loss and resonant frequency for the X/Ku band were found out.

With the help of an ANN, a better value for return loss and the resonant frequency is found out. Backpropagation is a method used to optimize the ANN. It is a multi-layer perceptron network. Four dependent variables (f_{down}, f_{upper}, $(S11)_{down}$, $(S11)_{upper}$) are the four input layers of neurons and four independent variables (D, R_1, R_2, W_2) are four output layers of the neuron [23], [24]. Number of hidden layers taken is 12 and the number of epochs is 2000. The ANN model is trained over different structures. It is observed the ANN-trained model performs better with its past experience.

2.2.2. Microstrip antenna miniaturization using genetic algorithm

Microstrip antenna size is decreasing due to the rapid reduction in the size of communication devices. The rectangular microstrip patch is divided into $n \times m$ small uniform rectangular cells. Each cell is either conducting material or nonconducting material. The cells are arranged in such a way that it gives the required output. The resonance frequency shift is the desired output for this optimization process [25]. Figure 4 depicts the view of miniaturized microstrip antenna.

A metal patch is divided into 10×10 number of square patches. A string of 20 random binary numbers is chosen to get the population in the process of GA optimization [26]. According to string, the binary one is represented with metal conducting materials, and binary 0 is replaced with nonconducting material on the antenna surface. The output for resonant frequency and return loss is calculated with the help of a software computer simulation technology (CST) [27], [28]. The cost function is calculated on the result obtained from CST with the help of MATLAB [29], [30].

$$cost = \left|\frac{1}{N}\sum_{i=1}^{N} Q(f_i)\right| \tag{6}$$

A new generation of the 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. A maximum of 5 bits are mutated in this process [31], [32]. The resonant frequency and return loss are found for a new generation and cost function is evaluated. The process crossover, mutation, fitness function evaluation continues till the desired result is found. The binary numbers contained in the final generation are our desired output. The binary numbers are applied to the antenna structure to generate an optimized solution. The frequency shifts from 4.9 to 2.16 GHz with the miniaturization shape of a rectangular microstrip antenna [33]. The optimized antenna could be dual-polarized and broadband. Different optimization process gives different optimized solutions that may be desired or not.

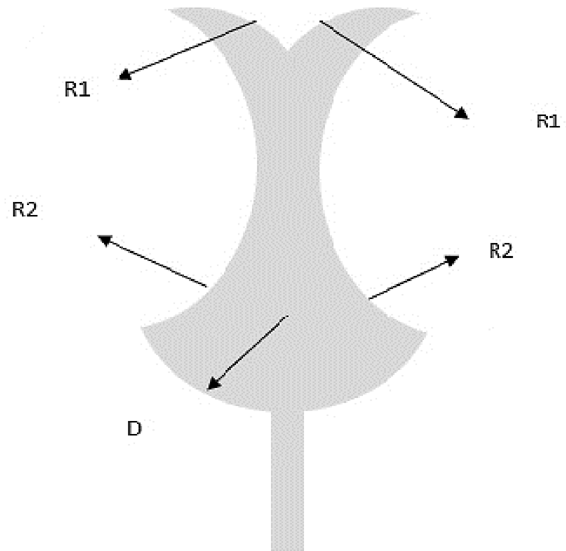

Figure 3. Tulip shaped microstrip antenna

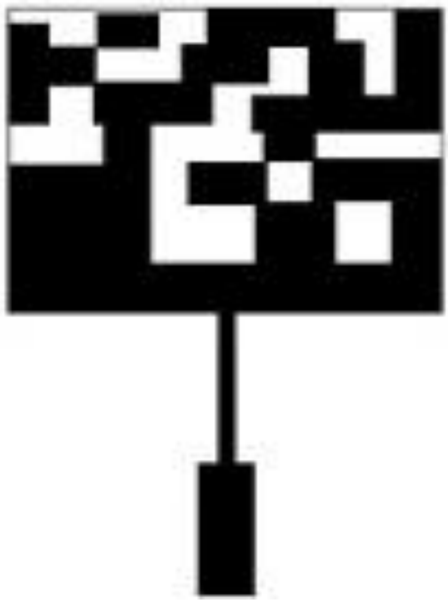

Figure 4. Miniaturized microstrip antenna

3. CONCLUSION

The optimized value of microstrip antennas is efficient irrespective of structures. The return loss obtained in this optimization process is always better than the non-optimize one. The optimized value of different algorithms is comparable. The result may vary and could be better for any other optimization algorithms. Optimization never limits the shape of antenna dimensions. Optimization modifies its dimension to get better results. The application of differential evolution, PSO, GA, and ANN 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. The area for future research includes the 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 be applied to the different structures of microstrip antenna such as slot antenna, antenna array, and parasitic antennas.

ACKNOWLEDGEMENTS

This research work was funded by "Woosong University's Academic Research Funding-2022".

REFERENCES

[1] H. M. Marhoon and N. Qasem, "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, p. 5546, Oct. 2020, doi: 10.11591/ijece.v10i5.pp5546-5558.

[2] A. Zaidi, A. Baghdad, A. Ballouk, and A. Badri, "Design and optimization of a high gain multiband patch antenna for millimeter wave application," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 5, pp. 2942–2950, Oct. 2018, doi: 10.11591/ijece.v8i5.pp2942-2950.

[3] O. O. Adedayo, M. O. Onibonoje, and O. M. Adegoke, "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, p. 5159, Dec. 2019, doi: 10.11591/ijece.v9i6.pp5159-5164.

[4] S. U. Khan, M. K. A. Rahim, M. Aminu-Baba, A. E. K. Khalil, and S. Ali, "Diagnosis of faulty elements in array antenna using aature inspired cuckoo search algorithm," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 3, p. 1870, Jun. 2018, doi: 10.11591/ijece.v8i3.pp1870-1874.

[5] M. Gangopadhyaya, P. Mukherjee, U. Sharma, B. Gupta, and S. Manna, "Design optimization of microstrip fed rectangular microstrip antenna using differential evolution algorithm," in *2015 IEEE 2nd International Conference on Recent Trends in Information Systems (ReTIS)*, Jul. 2015, pp. 49–52, doi: 10.1109/retis.2015.7232851.

[6] A. K. Hamid and W. Obaid, "Hexa-band MIMO CPW bow-tie aperture antenna using particle swarm optimization," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 5, p. 3118, Oct. 2018, doi: 10.11591/ijece.v8i5.pp3118-3128.

[7] B.-K. Ang and B.-K. Chung, "A wideband e-shaped microstrip patch antenna for 5-6 ghz wireless communications," *Progress In Electromagnetics Research*, vol. 75, pp. 397–407, 2007, doi: 10.2528/pier07061909.

[8] U. Ozkaya and L. Seyfi, "Dimension optimization of microstrip patch antenna in X/Ku band via artificial neural network," *Procedia - Social and Behavioral Sciences*, vol. 195, pp. 2520–2526, Jul. 2015, doi: 10.1016/j.sbspro.2015.06.434.

[9] J. Ayasinghe, J. A. Pros, and D. Uduwawala, "Genetic algorithm optimization of a high-directivity microstrip patch antenna having a rectangular profile," *Radioengineering*, vol. 22, no. 3, 2013.

[10] J. W. Jayasinghe, J. Anguera, and D. N. Uduwawala, "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, doi: 10.2528/pierm12102705.

[11] F. Afshinmanesh, A. Marandi, and M. Shahabadi, "Design of a singlefeed dual-band dual-polarized printed microstrip antenna using a boolean particle swarm optimization," *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 7, pp. 1845–1852, Jul. 2008, doi: 10.1109/tap.2008.924684.

[12] Nasimuddin, K. P. Esselle, and A. K. Verma, "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, doi: 10.1109/tap.2007.915476.

[13] P. Soontornpipit, C. M. Furse, Y. C. Chung, and B. M. Lin, "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, Mar. 2006, doi: 10.1109/tap.2006.869904.

[14] N. G. Alexopoulos, P. B. Katehi, and D. B. Rutledge, "Substrate optimization for integrated circuit antennas," *IEEE Transactions on Microwave Theory and Techniques*, vol. 31, no. 7, pp. 550–557, 1983, doi: 10.1109/tmtt.1983.1131544.

[15] K. R. Mahmoud, "Central force optimization: Nelder-mead hybrid algorithm for rectangular microstrip antenna design," *Electromagnetics*, vol. 31, no. 8, pp. 578–592, Nov. 2011, doi: 10.1080/02726343.2011.621110.

[16] C. A. Balanis, *Antenna theory: analysis and design*. John wiley & sons, 2016.

[17] G. Kumar and K. P. Ray, *Broadband microstrip antennas*. Artech, 2002.

[18] A. Deb, J. S. Roy, and B. Gupta, "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. 3920–3928, Aug. 2014, doi: 10.1109/tap.2014.2322880.

[19] S. V. R. S. Gollapudi *et al.*, "Bacterial foraging optimization technique to calculate resonant frequency of rectangular microstrip antenna," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 18, no. 4, pp. 383–388, May 2008, doi: 10.1002/mmce.20296.

[20] A. A. Minasian and T. S. Bird, "Particle swarm optimization of microstrip antennas for wireless communication systems," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 12, pp. 6214–6217, Dec. 2013, doi: 10.1109/tap.2013.2281517.

[21] M. T. Islam, N. Misran, T. C. Take, and M. Moniruzzaman, "Optimization of microstrip patch antenna using Particle swarm optimization with curve fitting," in *2009 International Conference on Electrical Engineering and Informatics*, Aug. 2009, pp. 711–714, doi: 10.1109/iceei.2009.5254724.

[22] M. H. Misran, S. K. A. Rahim, M. A. M. Said, and M. A. Othman, "A systematic optimization procedure of antenna miniaturization for efficient wireless energy transfer," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 4, p. 3159, Aug. 2019, doi: 10.11591/ijece.v9i4.pp3159-3166.

[23] O. Ozgun, S. Mutlu, M. I. Aksun, and L. Alatan, "Design of dual-frequency probe-fed microstrip antennas with genetic optimization algorithm," *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 8, pp. 1947–1954, Aug. 2003, doi: 10.1109/tap.2003.814732.

[24] M. Lamsalli, A. El Hamichi, M. Boussouis, N. A. Touhami, and T. Elhamadi, "Genetic algorithm optimization for microstrip patch antenna miniaturization," *Progress In Electromagnetics Research Letters*, vol. 60, pp. 113–120, 2016, doi: 10.2528/pierl16041907.

[25] A. Singh and S. Singh, "Design and optimization of a modified sierpinski fractal antenna for broadband applications," *Applied*

Soft Computing, vol. 38, pp. 843–850, Jan. 2016, doi: 10.1016/j.asoc.2015.10.013.
[26] A. A. Al-Azza, A. A. Al-Jodah, and F. J. Harackiewicz, "Spider monkey optimization: A novel technique for antenna optimization," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1016–1019, 2015, doi: 10.1109/lawp.2015.2490103.
[27] R. C. Mahajan, V. Vyas, and M. S. Sutaone, "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, p. 111156, Jan. 2020, doi: 10.1016/j.mee.2019.111156.
[28] F. M. Monavar and N. Komjani, "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, doi: 10.2528/pier11051305.
[29] A. Zaidi, A. Baghdad, A. Ballouk, and A. Badri, "Design and optimization of an inset fed circular microstrip patch antenna using DGS structure for applications in the millimeter wave band," in *2016 International Conference on Wireless Networks and Mobile Communications (WINCOM)*, Oct. 2016, pp. 99–103, doi: 10.1109/wincom.2016.7777198.
[30] E. Hassan, E. Wadbro, and M. Berggren, "Topology optimization of metallic antennas," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 5, pp. 2488–2500, May 2014, doi: 10.1109/tap.2014.2309112.
[31] R. J. Kavitha and H. S. Aravind, "An analytical approach for design of microstrip patch (MsP)," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 6, p. 4175, Dec. 2018, doi: 10.11591/ijece.v8i6.pp4175-4183.
[32] D. P. Mishra, K. K. Rout, and S. R. Salkuti, "Compact MIMO antenna using dual-band for fifth-generation mobile communication system," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 24, no. 2, pp. 921–929, Nov. 2021, doi: 10.11591/ijeecs.v24.i2.pp921-929.
[33] P. Palai, D. P. Mishra, and S. R. Salkuti, "Biogeography in optimization algorithms: a closer look," *IAES International Journal of Artificial Intelligence (IJ-AI)*, vol. 10, no. 4, pp. 982–989, Dec. 2021, doi: 10.11591/ijai.v10.i4.pp982-989.

BIOGRAPHIES OF AUTHORS

Kalpa Ranjan Behera received the M.Tech degree in electronics and communication engineering from the college of engineering and technology, Bhubaneswar, India, in 2020. He got an internship from Woosong University, South Korea, in 2021. He is currently working toward software technology with a private company. His research interests include wireless communication, microstrip antenna, artificial intelligence, Internet of Things. He can be contacted at email: kalparanjanbehera@gmail.com.

Surender Reddy Salkuti received the Ph.D. degree in electrical engineering from the Indian Institute of Technology, New Delhi, India, in 2013. He was a Postdoctoral Researcher with Howard University, Washington, DC, USA, from 2013 to 2014. He is currently an Associate Professor with the Department of Railroad and Electrical Engineering, Woosong University, Daejeon, South Korea. His current research interests include power system restructuring issues, ancillary service pricing, real and reactive power pricing, congestion management, and market clearing, including renewable energy sources, demand response, smart grid development with integration of wind and solar photovoltaic energy sources, artificial intelligence applications in power systems, and power system analysis and optimization. He can be contacted at email: surender@wsu.ac.kr.