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Optimized Microstrip Antennas with Metamaterial Superstrates using Particle Swarm Optimization

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Abstract

Two new designs of compact microstrip antennas, where metamaterials are placed on structure as superstrate, are proposed. The newly designed metamaterial unit cell and antenna feed position optimized by particle swarm optimization. It was found that the characteristics of novel microstrip antennas with designed metamaterials placed on the superstrate are comparable to the conventional patch antennas, while their gain, directivity and radiating efficiency are noticeably improved. Gain of microstrip antenna is increased 3dB to 4dB and level of back lobe is decresed.

Keywords: *microstrip, metamaterial, particle swarm optimization*

1. Introduction

Microstrip antenna has several excellent physical properties, such as light weight, low profile, low production cost, conformability, reproducibility and reliability, microstrip antennas (MSA) have been used in wireless communication equipments and solid state devices [1]. However, there are two major disadvantages associated with MSA: low gain and narrow bandwidth. Various techniques have been proposed to produce high directivity at broadside [2-3]. Amongst techniques for gain enhancement, one novel method is to include metamaterial onto antenna's superstrate. Several configurations of superstrates were used to improve antenna radiation properties, such as dielectric slabs [4], electromagnetic bandgap (EBG) structures [5], highly-reflective surfaces [6], and the most recently artificial magnetic superstrates [7].

Using magneto-dielectric materials with high positive permeability and permittivity values as the superstrate of microstrip patch antennas (MPA) decreases the wavelength in the media, leading to a lower profile of the whole structure [7]. In [8], the potential application of magneto-dielectric materials as a superstrate to improve the gain of MPA was investigated without considering physical realization of the artificial superstrate. Latrach et al. [9] used edge-coupled split ring resonator (SRR) inclusions to provide artificial superstrate comprising alternately layers with negative permeability and positive index of refraction materials to increase the gain of patch antenna. Here, we are interested in studying the performances of a single patch antenna when a left-handed medium (LHM) is placed above it.

Another problem in designing antenna is to determine the geometric parameters of the antenna, such as the patch dimensions and the feed position, to achieve the best design that satisfies a certain criterion. Many efforts have been expanded on the parametric study of various patch antennas [10]. However, these studies are not systematic and the conclusions are highly dependent on the antenna under investigation. Consequently, a trial-and-error process is inevitable in most patch antenna designs.

Recently the particle swarm optimization (PSO) was introduced to the EM community [11] to accommodate this challenge. The initial PSO concept was developed in 1995 [12] as a novel evolutionary optimization(EO) methodology over a complex solution space.PSO starts by designing each position in the solution space as a potential design.A fitness function is then defined to quantify the performance of each design. Compared to conventional EO algorithms such as the genetic algorithm (GA) [13], PSO takes the advantage of its algorithmic simplicity and robustness. PSO has been applied to many EM applications, such as the one-dimensional (1-D)

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and 2-D array synthesize [14-16], the corrugated horn design [17], and the reflector shaping [18]. The multiobjective optimizations [16, 19, 20] further enhance the performance of PSO by exploiting its inherit versatility and using multiple fitness functions [rahmatescholar].

In this paper a rectangular patch antennas loaded by new metamaterial structure that operating as LHM medium in order to miniaturize the patch antenna and increase the radiation patterns are proposed.

The proposed metamaterial structure printed on a dielectric substrate with permittivity ε_r=2.2. The unit cell is simulated by Ansoft HFSS and MATLAB and the results are described. PSO is applied in optimization of unit cells of metamaterial and position of coaxial cable and the better answers are selected to use in patch antenna.

In the next part, a new miniaturized rectangular patch antenna is proposed. It is shown that in antenna with 9 number of first unit cells and 6 number of second structures the size reduction is about 40% and 30%, respectively. Also the return loss of these antennas are noticeably reduced.

2. PSO Algorithm Architecture

The original PSO formulae defined each particle as a potential solution to a problem in D-dimensional space, with particle i represented X_i.

Each particle also maintains a memory of its previous best position, P_i and a velocity along each dimension, represented as V_i At each iteration, the P vector of the particle with the best fitness in the local neighborhood, designated *g*, and the P vector of the current particle are combined to adjust the velocity along each dimension, and that velocity is then used to compute a new position for the particle.

The portion of the adjustment to the velocity influenced by the individual's previous best position (P) is considered the cognition component, and the portion influenced by the best in the neighborhood is the social component [21]-[23]. In Kennedy's early versions of the algorithm, these formulae are:

$$v_{id} = v_{id} + j_1 * rand() * (p_{id} - x_{id}) + j_2 * rand() * (p_{id} - x_{id}) \quad (1)$$

$$x_{id} = v_{id} + x_{id} \quad (2)$$

Constants j 1 and j 2 determine the relative influence of the social and cognition components, and are often both set to the same value to give each component (the cognition and social learning rates) equal weight.

A constant, V_{max}, was used to arbitrarily limit the velocities of the particles and improve the resolution of the search [24]. Eberhart and Shi show that PSO searches wide areas effectively, but tends to lack local search precision [25]. Their solution in that paper was to introduce w, an inertia factor , that dynamically adjusted the velocity over time, gradually focusing thePSO into a local search:

$$v_{id} = w * v_{id} + j_1 * rand() * (p_{id} - x_{id}) + j_2 * rand() * (p_{id} - x_{id}) \quad (3)$$

More recently, Maurice Clerc has introduced a constriction factor [26], ***K***, that improves PSO's ability to constrain and control velocities. In [27], Shi and Eberhart found that *K*, combined with constraints on V_{max}, significantly improved the PSO performance. K is computed as:

$$k = \frac{2}{\left|2-\varphi-\sqrt{\varphi^2-4\varphi}\right|} \quad (4)$$

$$\varphi = \varphi_1 + \varphi_2 \quad (5)$$

Finally, the PSO formulae is:

$$v_{id} = v_{id} + \varphi_1 * rand() * (p_{id} - x_{id}) + \varphi_2 * rand() * (p_{id} - x_{id}) \quad (6)$$

3. Unit Cell Design

The proposed metamaterial unit cells are shown in Figure 1. PSO optimizes g which is playing key role in reducing return loss.

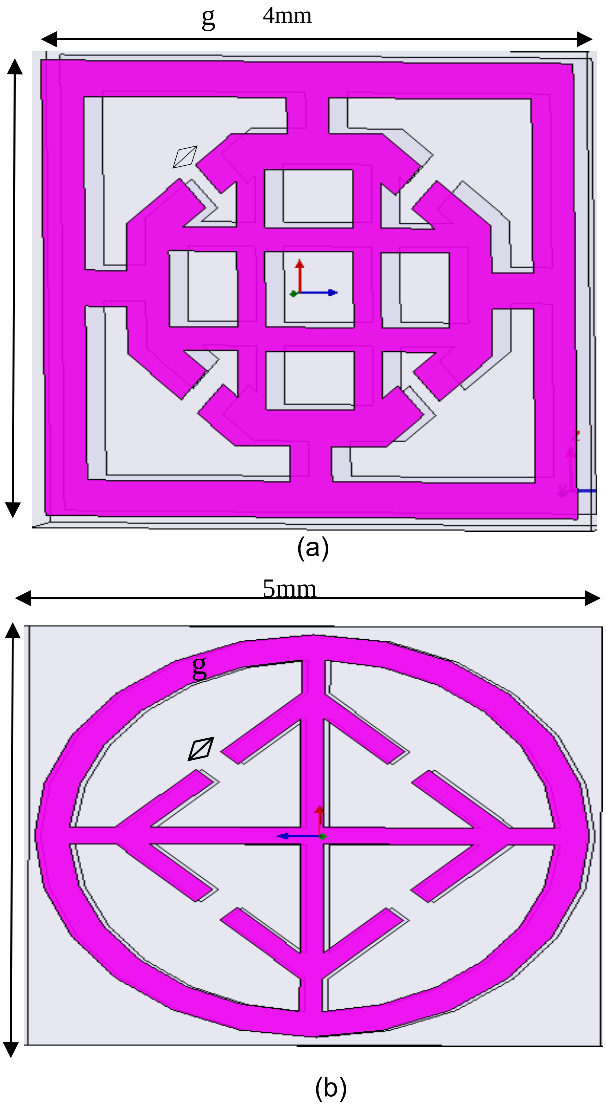


Figure1. Dimension of (a) first (b) second unit cell

For the simulation of the unit cell in HFSS, boundary conditions of magnetic and electric wall are applied respectively according to axes y and x. The structure is polarized so that the magnetic field is directed along x axis, the electric field is directed along y axis, the wave vector is according to the z axis. The Simulation is made on a frequency band between 6GHz and 16GHz with a 0.01GHz increment. The simulated S parameters for these structures are shown in Figure 2 and Figure 3, respectively.

As shown in Figure 2, there is a transmission peak around 12.7GHz, which indicates the existence of a resonance frequency which is due to the capacitive effect created by the geometry of the structure. So, we have an LC resonator, who has a resonance frequency which depends only on the inductance and capacitance of the equivalent structure, where:

$$\omega = \frac{1}{\sqrt{LC}} \quad (7)$$

The second unit cell show resonance behavior around 16.2GHz.

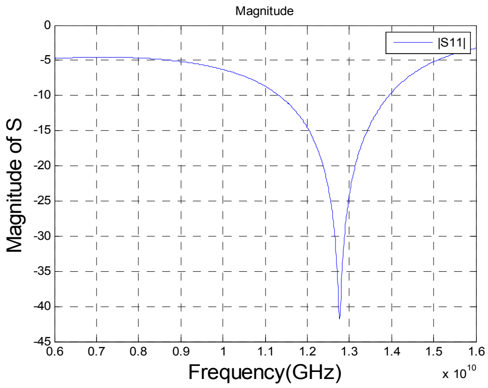


Figure 2. Return Loss of the First Unit Cell

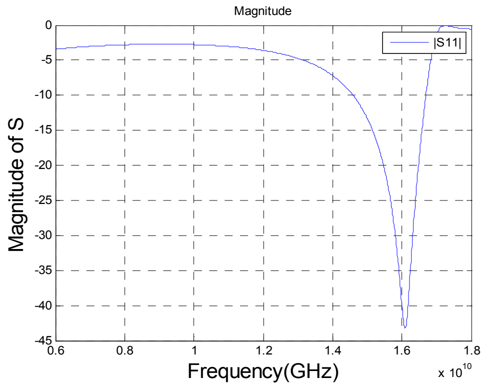


Figure 3. Return Loss of the Second Unit Cell

4. PSO OPTIMIZATION

In these cases, Visual Basic Script (VBS) is used as an interface between MATLAB and HFSS. Optimized unit cells return loss compared with unit cells that were originally designed in Figure 4. This will ultimately increase the gain of microstripantenna, which array of unit cells are placed as superstrate.

Optimization algorithms can be reduced significantly the return losses that will be causes 25dB and 15dB loss reduction of the first and the second unit cell, respectively.

The initial value for g in the first and second unit cell is 0.15mm, 0.3mm, respectively. Optimization has been performed 100 times and optimized value is 0.3mm for the first unit cell and 0.42mm for the second unit cell.

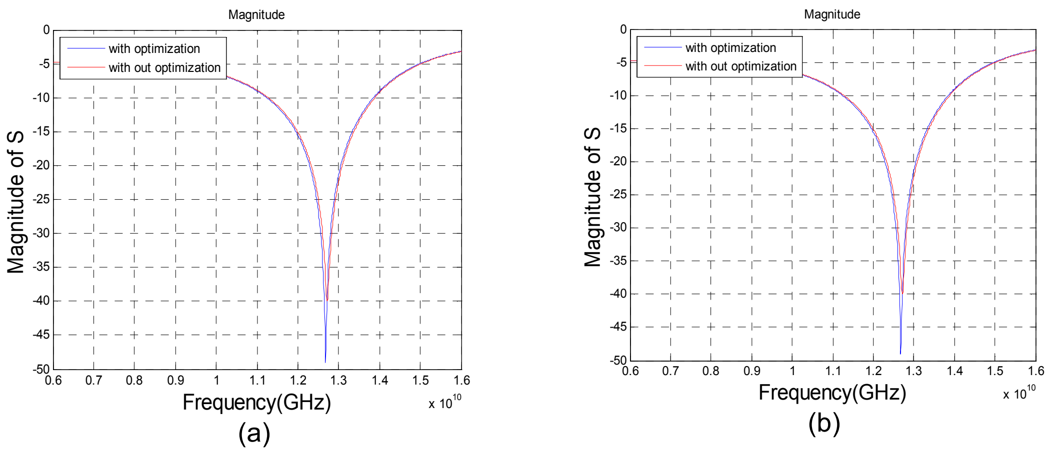


Figure 4. Optimization of the g for (a) the first unit cell (b) the second unit cell

5. Extract Permittivity and Permeability

The effective permittivity ε_{eff} and permeability μ_{eff} of the structure can be found from the refractive index *n* and wave impedance *Z* as Equation (8) and (9), respectively.

$$\varepsilon_{eff} = n/Z \tag{8}$$

$$\mu_{eff} = n \times Z \tag{9}$$

Where *n* and *Z* can be determined from the measurement ofthe reflection coefficients and transmission coefficients [28, 29] of a wave normally incident on a slab of the metamaterial, followed by the application of a retrieval algorithm [30].

As shown in Figure 5(a), the real part of the permeability of the first unit cell shows Lorentz response behavior, it is negative in the 12.7GHz. In addition, the permittivity real part is negative in the frequency in 12.7GHz, which is in good agreement with the Drude model as it appears on the Figure 5(b).

As shown in Figure 6 negative real parts of the permittivity and permeability lies in the negative band (1.6−1.8GHz). Also, the permittivity and permeability show Drude and Lorentz response behavior in the studied frequency region, respectively [31-32].

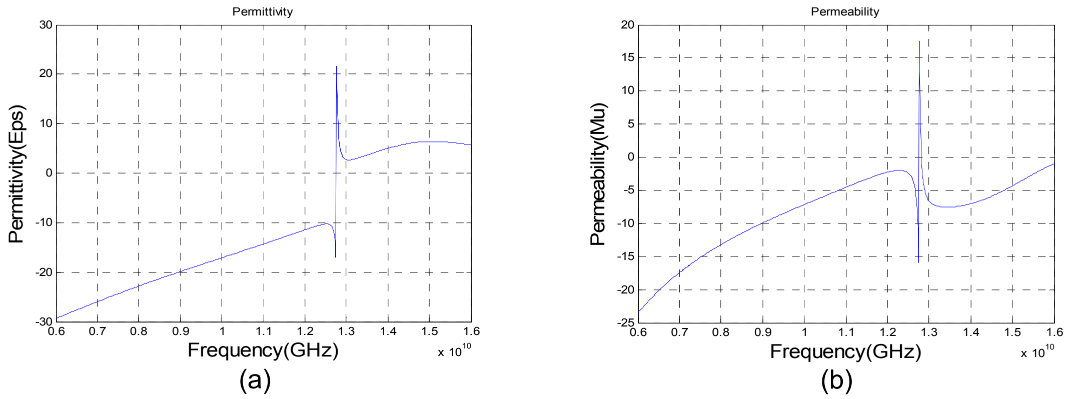


Figure 5. (a) Permeability (b) permittivity of the first unit cell

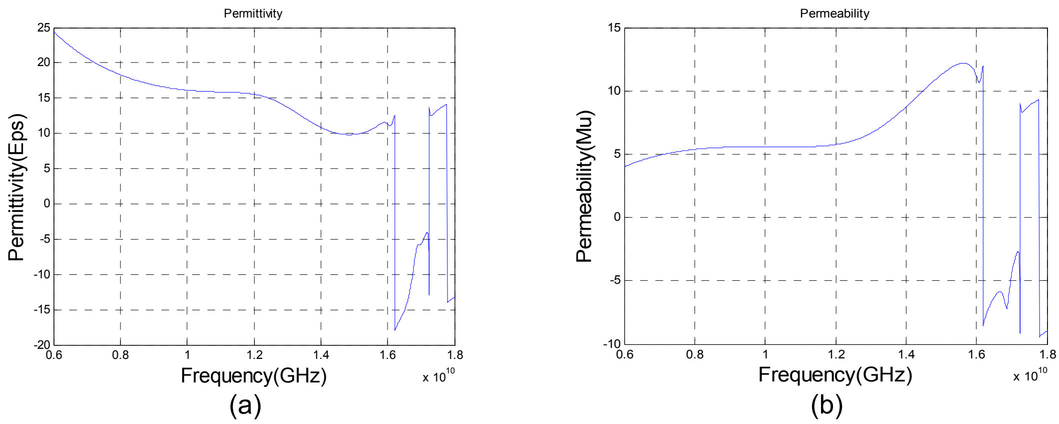


Figure 6. (a) Permeability (b) permittivity of the second unit cell

6. Antenna Structure

The first step in designing the antenna is position of a coaxial cable. The importance of this is that the input impedance can be matched to 50Ω. One method is to use a microstrip quarterwave matching section, printed on the same substrate, which matches the edge impedance to 50Ω.

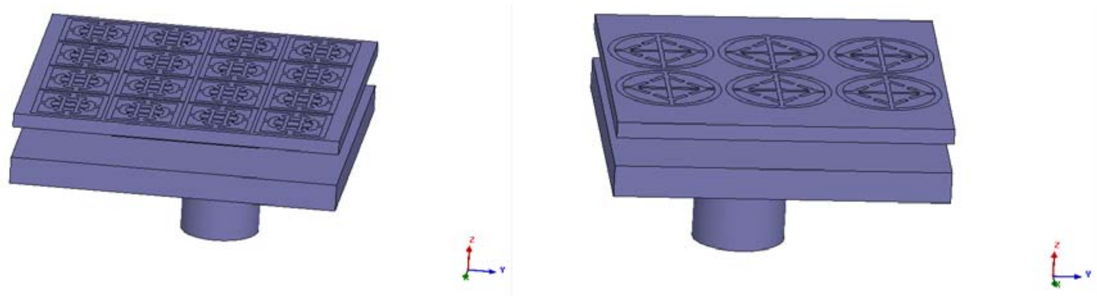
However, the microstrip matching section is itself a radiating element due to the discontinuity in line width, and the radiation from it may add to that of the antenna in ways that are difficult to determine.

In this paper feed position initialized by Computer Aided Design (CAD) formulae [33] then, PSO find the best position. The results of the optimization algorithm for 12.7GHz and 16.2GHz are 11.4mm and 7.2mm, respectively.

Table 1. Dimension of Antenna

Frequency	Patch Dimension	Substrate Dimension
12.7GHz	6.9mm×7.9mm	16.5mm×17.8mm
16.2GHz	5mm×5.7mm	14.6mm×15.3mm

After this step, dimensions of substrate and rectangular patch due to resonance frequency are calculated. These values are shown in Table 1. The thick ness of substrate is 1.6mm and permittivity is 2.2. As shown in Figure 7(a), a 4×4 array of the first unit cell is placed above the patch antenna. The gain of the antenna as shown in Figure 7(a). The second structure of metamaterial is used as a 3×2 array above the patch antenna as shown in Figure 7(b).

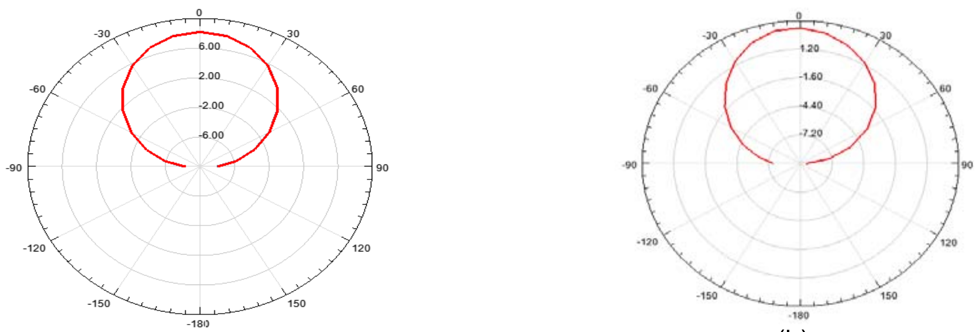


(a) (b)

Figure 7. Configuration of the Patch Antenna Using (a) the first unit cell, (b) the second unit cell

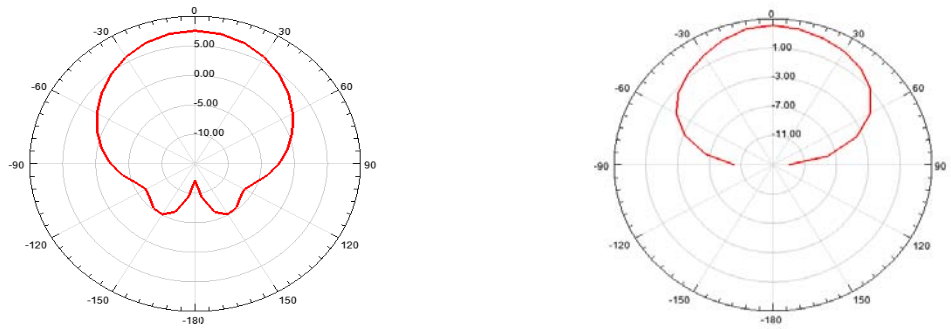
The simulated antenna present a return loss -23dB around GHz and the gain is 8dB.The distance between superstrate and rectangular patch is about quarter of wave length. Thickness and permittivity is the same as previous structure.

The maximum return loss of this antenna is -25dB and gain is 7.3dB. As shown in Figure 8(a) and 9(a), the gain of the antenna which is used the first structure is higher than the second structure. Gain of patch antennas which resonate at 12.7GHz and 16.2GHz are shown in Figure 8(b) and 9(b),respectively.



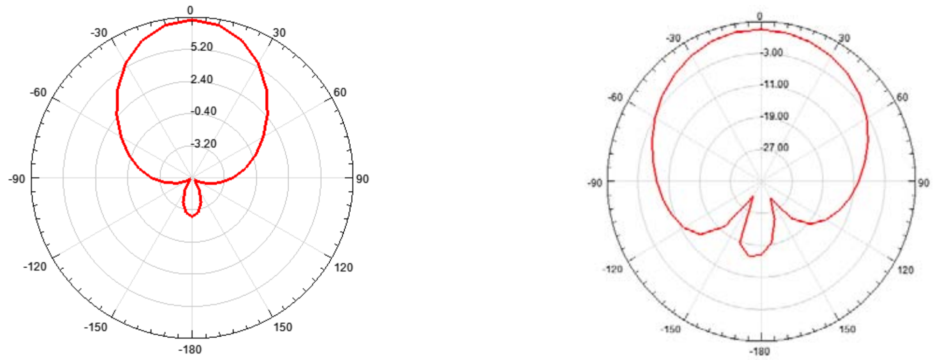
(a) (b)

Figure 8. Gain of the Microstrip Patch Antenna (a) using the first unit cell, (b) without metamaterial



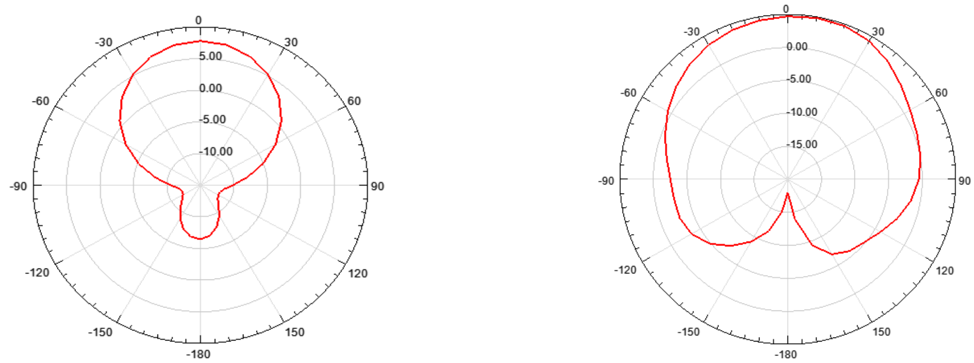
(a) (b)

Figure 9. Gain of the Microstrip Patch Antenna (a) using the second unit cell, (b) without metamaterial



(a) (b)

Figure 10. Directivity of the Microstrip Patch Antenna (a) using the first unit cell, (b) without metamaterial



(a) (b)

Figure 11. Directivity of the Microstrip Patch Antenna (a) using the second unit cell, (b) without metamaterial

Directivity of the first and second antenna which is used metamaterial as a superstrate is compared with antenna without superstrate are shown in Figure 10 and 11, respectively. Directivity is increased significantly and level of back lobe is reduced. By comparing these figures, we can conclude optimized metamaterials enhance the gain and directivity and reduced level of back lobe, significantly. This makes one of the major disadvantages of microstrip antenna and improves its performance at microwave frequencies.

7. Conclusion

Metamatrial unit cells are optimized and placed on conventional microstrip antennas. These design and placement enhance the radiation pattern; hence the gain and directivity of the microstrip are improved. The location of the operating frequency is tuned effectively by the magnetic resonance of the structures.This technique can be another option employed to reduce the size of patch antenna and better efficiency simultaneously.

References

[1] V Rani Gupta, N Gupta. Two Compact Microstrip Patch Antennas for 2.4 GHz Band-A Comparison. *Microwave Review*. 2006; 12(2).

[2] DR Jackson, NG Alexopoulos. Gain enhancement methods for printed-circuit antennas. *IEEE Trans. Antennas Propag*., 1985; AP-33(9): 976-987.

[3] KJ Vinoy, KA Jose, VK Varadan, VV Varadan. Gain enhanced electronically tunable microstrip patch antenna. *Microw. Opt. Technol. Lett.,* 1999; 23(6): 368–370.

[4] H Vettikalladi, O Lafond, M Himdi. High-efficient and high-gain superstrate antenna for 60-ghz indoor communication. *IEEE Antenna Wireless Propagat. Lett.*, 2009; 8; 1422–1425.

[5] H Attia, OM Ramahi. *EBG superstrate for gain and bandwidth enhancement Ofmicrostrip array antennas.* Proceeding of IEEE AP-S Int. Symp. Antennas Propagat., San Diego, CA. 2008; 1–4.

[6] A Foroozesh, L Shafai. Investigation into the effects of the patchtypefsssuperstrate on the high-gain cavity resonance antenna design. *IEEE Trans. Antennas Propagat.,* 2010; 58(2): 258–270.

[7] H Attia, L Yousefi, MM Bait-Suwailam, MS Boybay, OM Ramahi. Enhanced-gain microstrip antenna using engineered magnetic superstrates. *IEEE Antenna Wireless Propagat. Lett.,* 2009; 8; 1198–1201.

[8] A Foroozesh, L Shafai. *Size reduction of a microstrip antenna with dielectric superstrate using meta-materials: Artificial magnetic conductors versus magneto-dielectrics*. Proceeding of IEEE AP-S Int. Symp. Antennas Propagat., Albuquerque, NM. 2006; 11–14.

[9] M Latrach, H Rmili, C Sabatier, E Seguenot, S Toutain. *Design of a new type of metamaterialradome for low frequencies*. Proceeding of META08 and NATO Adv. Rese. Workshop: Metamater. Secure Inf. Commun. Technol., Marrakesh, Morocco. 2008; 202211.

[10] S Weigand, GH Huff, KH Pan, JT Bernhard. Analysis and design of single-layer rectangular u-slot microstrip patch antennas. *IEEE Trans. Antennas Propag.,* 2010; 51(3): 457-4682003.

[11] J Robinson, Y Rahmat Samii. Particle swarm optimization in electromagnetic. *IEEE Trans. Antennas Propag.,* 2004; 52(2): 397–407.

[12] J Kennedy, R Eberhart. *Particle swarm optimization.* Proc. Int. Conf. Neural Networks, vol. IV, Perth, Australia. 1995; 1942–1948.

[13] Y Rahmat Samii, E Michielssen, Eds., Electromagnetic Optimizaion by Genetic Algorithms. New York: Wiley. 1999.

[14] D Gies, Y Rahmat Samii. Particle swarm optimization for recongurable phase differentiated array design. *Microw.Opt.Technol.Lett.,* 2003; 38(3): 172–175.

[15] D Boeringer, D Werner. Particle swarm optimization versus genetic algorithms for phased array synthesis. *IEEE Trans Antennas Propag.,* 2004; 52(3): 771–779.

[16] D Gies, Y Rahmat Samii. Vector evaluated particle swarm optimization (VEPSO): Optimization of a radiometer array antenna. *IEEE Antennas Propagat. Soc. Int. Symp. Dig.,* 2004; 3: 2297–2300.

[17] J Robinson, S Sinton, Y Rahmat Samii. Particle swarm, genetic algorithm, and their hybrids: Optimization of a proled corrugated horn antenna. *IEEE Antennas Propagat. Soc. Int. Symp. Dig.,* 2002; 1: 314–317.

[18] D Gies, Y Rahmat Samii. Particle swarm optimization (PSO) for reector antenna shaping. *IEEE Antennas Propagat. Soc. Int. Symp. Dig.,* 2004; 3: 2289–2293.

[19] C Coello, G Pulido, M Lechuga. Handling multiple objectives with particle swarm optimization. *IEEE Trans. Evol. Comput.,* 2004; 8(3): 256–279.

[20] D Gies. Particle swarm optimization: Applications in electromagnetic design. M. S., Univ. California, Los Angeles, 2004.

[21] Eberhart R, Kennedy J. *A New Optimizer Using Particle Swarm Theory*. Proc. Sixth International Symposium on Micro Machine and Human Science (Nagoya, Japan), *IEEE Servic*e Center, Piscataway, NJ. 1995; 39-43

[22] Kennedy J. *The Particle Swarm: Social Adaptation of Knowledge*. IEEE International Conference on Evolutionary Computation (Indianapolis, Indiana), *IEEE Service Center,* Piscataway, NJ. 1997; 303-308.

[23] Kennedy J, Eberhart R. *Particle Swarm Optimization*. IEEE International Conference on Neural Networks (Perth, Australia), *IEEE Service Center,* Piscataway, NJ. 1995; IV: 1942-1948.

[24] Angeline P. *Evolutionary Optimization versus Particle Swarm Optimization: Philosophy and Performance Difference.* The 7th Annual Conference on Evolutionary Programming, San Diego, USA. 1998.
[25] Shi YH, Eberhart RC. *Parameter Selection in Particle Swarm Optimization.* The 7th Annual Conference on Evolutionary Programming, San Diego, USA. 1998.
[26] Clerc M. *The swarm and the queen: towards a deterministic and adaptive particle swarm optimization.* Proceedings, 1999 ICEC, Washington, DC. 1999; 1951-1957.
[27] Eberhart RC, Shi Y. *Comparing Inertia Weights and Constriction Factors in Particle Swarm Optimization*. Congress on Evolutionary Computing. 2000; 1: 84-88.
[28] Kong JA. *Electromagnetic wave interaction with stratified negative isotropic media*. Progress In Electromagnetics Research. 2002; 35: 1-5.
[29] Smith DR, Schultz S, Markos P, Soukoulis CM. Determination of permittivity and permeability of metamaterials from scattering data. *Phys. Rev. B*. 2002; 65(195104): 1-5.
[30] Chen X, Grzegorczyk TM, WuB I, Pacheco J, Kong JA. Robust method to retrieve the constitutive effective parameters of metamaterial. *Phys. Rev. E.* 70(016608): 1-7.
[31] Shelby RA, Smith DR, SchultzS. Experimental verification of a negative index of refraction. *Science*. 2001; 292: 77-79.
[32] Ziolkowski RW, Heyman E. Wave propagation in media havingnegative permittivity and permeability. *Physical Review E*. 2001; 64(056625): 1–15
[33] Pozar DM. Personal Computer Aided Antenna Design. Ver. 2.1. Antenna Design Associates, Leverett, MA. 1985.