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DESIGN OF AN E-SHAPED MIMO ANTENNA USING IWO ALGORITHM FOR WIRELESS APPLICATION AT 5.8 GHz

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Abstract—A novel compact four element multiple input multiple output (MIMO) antenna is proposed. The antenna is composed of four E-shaped patch elements and operates at 5.8 GHz. The single E-shaped patch antenna, operate at this frequency is designed using the Invasive Weed optimization algorithm. This algorithm is then applied to design the selected orthogonal polarization arrangement for two and four element MIMO antenna for high degree of isolation. In order to measure the array performance under MIMO signaling conditions a multi-port metric is used to characterize the compact array rather than the scattering matrix characterization. The designed antennas have low profile, easy fabrication, low cost and good isolation. The simulation and measurement results of reflection coefficient, mutual coupling and radiation pattern are presented.

1. INTRODUCTION

Multi-Input Multi-Output (MIMO) antenna systems have attracted considerable interest as an effective way of improving reliability and increasing the channel capacity [1]. MIMO antennas are suitable for the 4th generation mobile communication systems requiring high speed and high quality transmission involving large amount of data transfer. Wireless LAN systems that employ MIMO technology and achieve data transmission speeds of greater than 100 Mbits/sec have been reported in [2]. The use of MIMO technology in small terminals causes high degree of coupling and spatial correlation between antenna elements thus affecting the MIMO channel capacity.

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The primary aim of MIMO antenna design is to reduce correlation between received signals. A significant parameter for the correlation is the mutual coupling since it may marginally change the performance of the system especially at the receiver end. Mutual coupling describes the electromagnetic interactions that exist between antenna elements of an antenna array. One consequence of these interactions is the distortion of the radiation pattern of each element of the multi-element system compared to the radiation pattern of each isolated element. Higher mutual coupling may result in lower antenna efficiencies and higher correlation coefficients. The effect of mutual coupling on capacity of MIMO wireless channels is studied in [3]. One of the most critical parameter affecting mutual coupling and correlation is due to spacing between the elements, spatial diversity. Analytical studies have shown that for minimal or no mutual coupling, the distance between typical antenna elements needs to be at least half wavelength [4]. A dual-element planar inverted-F antenna (PIFA) array operating at 5.2 GHz is reported in [5, 6] to obtain an isolation better than 28 dB and correlation less than 0.01. This was obtained with a separation between elements of 20 mm equivalent to 0.35λ which is less than half wavelength. A dual-element PIFA operating at 2.5 GHz is studied in [7] with separation between elements at 20 mm resulting in an isolation of better than -20 dB. [8, 9] report the design of a novel compact 2 and 4 elements triband PIFA (at 2.45, 5.2 & 5.8 GHz) for use in portable MIMO enabled devices. Good results were obtained for the 2 element array but for the 4 element array with spacing set at 8 mm leads to some -7 dB isolation at 2.45 GHz.

The second parameter that can affect the correlation between the received signals is the radiation pattern of the antennas, pattern diversity. The implementation of a combination of orthogonal radiation pattern antennas, which leads to low antenna correlation characteristics in a compact configuration, is given in [28].

The third parameter that affects the correlation between the received signals is the polarization of the antennas, polarization diversity. A small three-port MIMO antenna with low profile (the size of a PCMCIA card) is reported in [10] that employs a modified inverted F antenna with an H-shaped conductor plate for the vertical polarization and two orthogonal notch antennas for the horizontal polarization (different patterns and polarizations) leading to low spatial correlation with coupling level less than -11.5 dB. The effects of spatial and polarization diversity on mutual coupling, correlation coefficient and total active reflection coefficient (TARC) of a MIMO array is analyzed in [11]. In that paper pattern and polarization diversity are shown to lead to better results even in the case where space is limited.

This paper, based on orthogonal polarization diversity, introduces a new low profile four channel MIMO antenna with good isolation and simple to fabricate. The antenna element is in the shape of a E and its dimensions are obtained through the Invasive Weed optimization, IWO algorithm [12].

Section 2 details the architecture of IWO algorithm. Section 3 utilizes the optimization of the E-shaped patch antennas to illustrate the IWO concept which represents the optimizations in a 5-D solution space. In Section 4, a configuration of two element E-shaped patch MIMO antenna is proposed. Orthogonal polarization arrangement is selected to lower the correlation between two antenna elements. In order to study the performance of the MIMO antenna, mutual coupling and total active reflection coefficient are considered. The results of the optimal antenna is presented and discussed. In Section 5, four-element antenna array is designed using a pair of two-element antenna array. This four channel MIMO antenna is optimized through IWO algorithm to have good reflection coefficient and isolation. The proposed optimized antenna is fabricated and results are obtained. The simulated results show reasonable agreement with the measured results.

2. INVASIVE WEED OPTIMIZATION (IWO) ALGORITHM

Recently, in the literature there has been a considerable attention paid to algorithms inspired from natural processes in order to solve an antenna optimization problem. Genetic algorithm [13–17], particle swarm optimization [18–21] and ant colony [22, 23] are such methods that have already been used.

Another algorithm is the Invasive Weed Optimization that was first proposed by Mehrabian and Lucas [12] in dynamic and control system theory.

IWO is a novel numerical stochastic optimization algorithm inspired by colonizing weeds. In [12], IWO is compared with genetic algorithms (GAs), memetic algorithms (MAs), particle swarm optimization (PSO), and shuffled frog leaping (SFL). The experimental studies suggest that results from IWO are as good as (in some cases are better than) results from other methods. It is shown in simulations that the proposed algorithm can capture properties of colonizing weeds fairly well and is capable of finding desired minima very fast in comparison with other stochastic search algorithms. As an optimization algorithm, it has the additional desirable properties of capability to deal with complex and non-differentiable objective functions and escapes from local optima. In conclusion, the performance of IWO is comparable with other evolutionary algorithms and IWO results are satisfactory for all test functions.

The feasibility, efficiency and effectiveness of the proposed algorithm for optimization of antenna problems were then examined

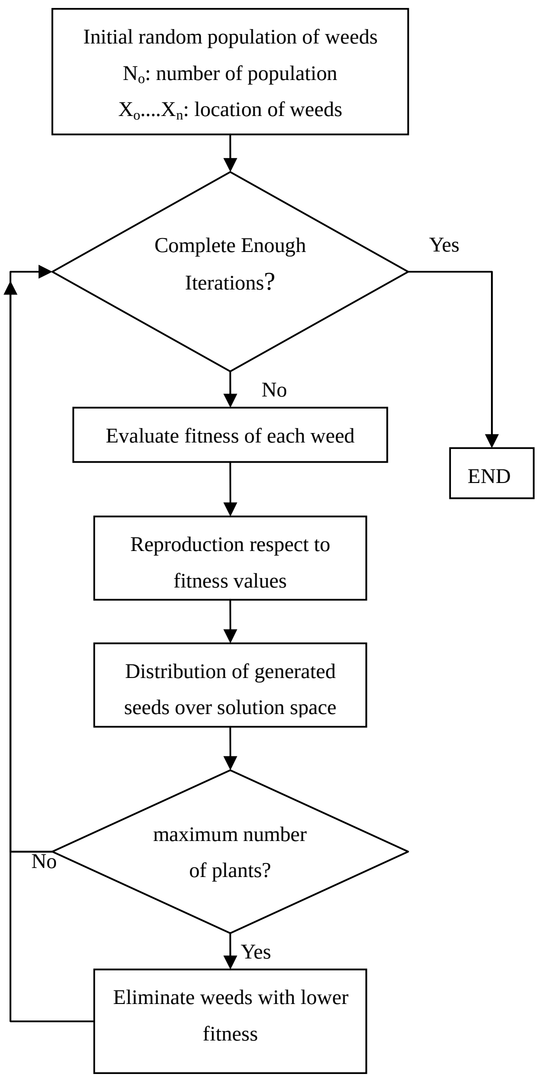

Figure 1. Flow chart depicting the IWO algorithm.

in [24] for a set of antenna configurations. In this paper, we will use the IWO algorithm to design the proposed antenna configuration. The basic steps towards the use of IWO as suggested by [12] are shown pictorially in Fig. 1.

3. IWO OPTIMIZATION OF SINGLE E-SHAPED PATCH ANTENNA

3.1. Antenna Geometry and Optimization Setup

E-shaped patch antenna is made by cutting two rectangular shaped slots on the edge of a rectangular patch. The configuration of an E-shaped patch antenna is shown in Fig. 2. The geometrical parameters are also labeled in the figure. The antenna is fed by a 50 Ω coaxial probe through a SMA connector at position $x = 3.4$ mm. The ground plane is fixed at 25 mm × 25 mm, and a 3.2-mm-thick Rogers RT/duroid5880 substrate is used. The IWO algorithm is then applied to optimize the E-shaped antenna in order to have the best impedance matching at resonant frequency of 5.8 GHz.

Table 1. IWO parameters values for E-shaped patch antenna.

Symbol	Quantity	Value
NO	Number of initial population	5
$It_{\max}$	Maximum number of iterations	220
Dim	Problem dimension	3
$P_{\max}$	Maximum number of plant population	15
$S_{\max}$	Maximum number of seeds	5
$S_{\min}$	Minimum number of seeds	0
n	Nonlinear modulation index	3
σ_{initil}	Initial value of standard deviation	3
σ_{final}	Final value of standard deviation	0.001
L_{ini}	Initial search area	0.02λ to 0.4λ

To start the optimization process, we should pick the parameters that need to be optimized and give them a reasonable range in which to search for the optimal solution. This requires specification of the minimum and maximum values for each dimension in a 5-dimensional optimization. This is referred to as L_{ini}. Then a good function must be

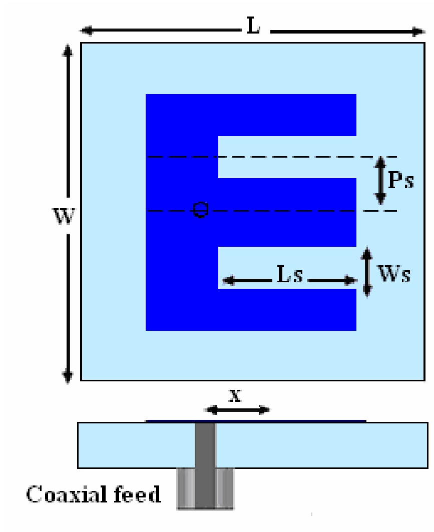

Figure 2. Configuration of an E-shaped patch antenna.

chosen, which accurately represents, in a single number, the goodness of the solution. In this problem, the shape of the E-patch is the solution and as shown in Fig. 2, the geometrical parameters to be optimized are: the patch length L, the patch width W, the slots length L_s, the slots width W_s and the position of slot P_s. For single E-shaped patch antenna, the return loss at the desired frequencies is optimized (i.e., the fitness function) using $f = \max(|S_{11}|, \text{at } f = 5.8\,\text{GHz})$. Setup of IWO algorithm for minimization of this function is specified in Table 1. To maintain the E-shaped structure, the following conditions must also hold as the additional geometrical restrictions

$$L_s \prec L \quad \text{The slot can not cross the patch.} \tag{1}$$

$$P_s \succ W_s/2 \quad \text{The central stub must be exist.} \tag{2}$$

$$P_s + W_s/2 \prec W/2 \quad \text{The top and bottom stubs must exit.} \tag{3}$$

$$X_p + \frac{L}{2} \succ L_s \quad \text{The feed can not go beyond the patch.} \tag{4}$$

Equations (2)–(5) completely defines the boundary of the solution space.

3.2. Optimization Results

The optimized geometric parameters obtained are listed in Table 2. Figs. 3 and 4 illustrate the convergence results of the optimization.

Table 2. Geometrical parameters of the optimized E-shaped patche antenna (Unit: Millimeters).

Parameter	L	W	Ls	Ws	Ps
Single E-shaped patch antenna	15.75	14.25	6.33	3.39	3.06

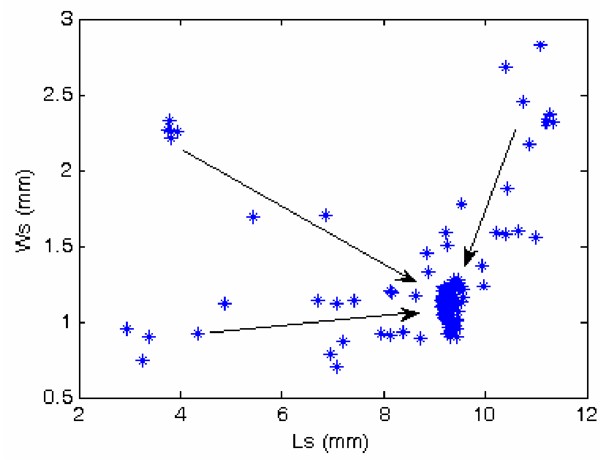

Figure 3. Simulated S_{11} curve of the optimized E-shaped patch antenna. Antenna resonates at $f = 5.8\,\text{GHz}$.

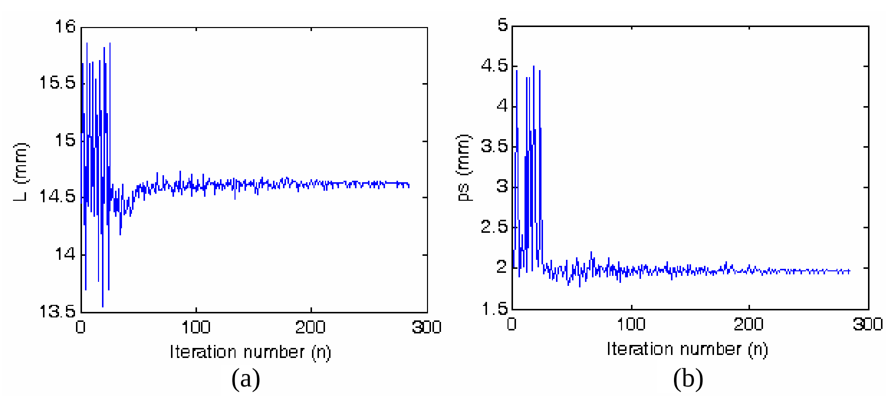

Figure 4. Convergence results of E-shaped patch antenna designs. (a) Variations of length of patch versus iteration number. (b) Variations of position of slot versus iteration number.

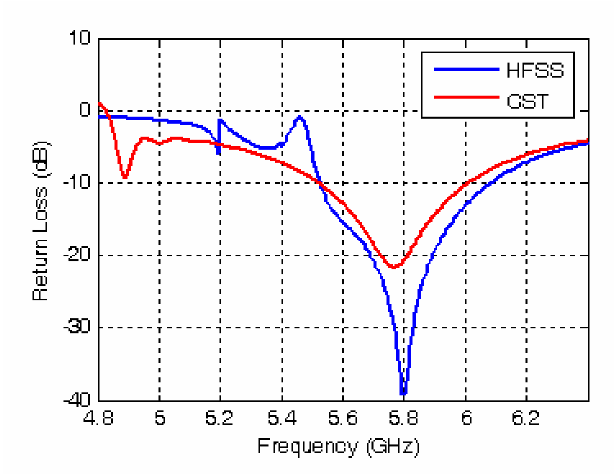

Figure 5. Simulated S_{11} curve of the optimized E-shaped patch antenna. Antenna resonates at $f = 5.8\,\text{GHz}$.

The simulated S_{11} curve by CST and HFSS is shown in Fig. 5. As can be seen from this figure, the antenna resonates at 5.8 GHz, so the goal of optimization has been satisfied. Fig. 6 shows the radiation pattern of the optimized E-shaped patch antenna.

4. TWO-ELEMENT MIMO ANTENNA

An E-shaped patch antenna is relatively robust to influence from another nearby E-shaped antenna. This makes it an ideal candidate for use in compact array designs. In this paper, a two-element antenna array configuration is proposed in Fig. 7 using the two antenna elements of Fig. 2. In order to have orthogonal polarization, the two antennas have been arranged at 90 degree angle to each other. The E-shaped antenna array elements are separated by 7 mm (0.13λ) and dimensions of the E-patches are determined so that they satisfy the goal of optimization. Since it is for two and four element antenna array, our design goal is to improve the isolation between antenna's ports, the fitness function in the IWO algorithm should contain mutual coupling between array elements. The mutual coupling between the antennas can be obtained from S_{ij} of the scattering matrix. The scattering matrix does not accurately characterize the radiation efficiency and bandwidth of a MIMO antenna [13]; instead of S matrix, the array's Total Active Reflection Coefficient (TARC) can be used so that it accounts for both coupling and random signal combination. TARC is

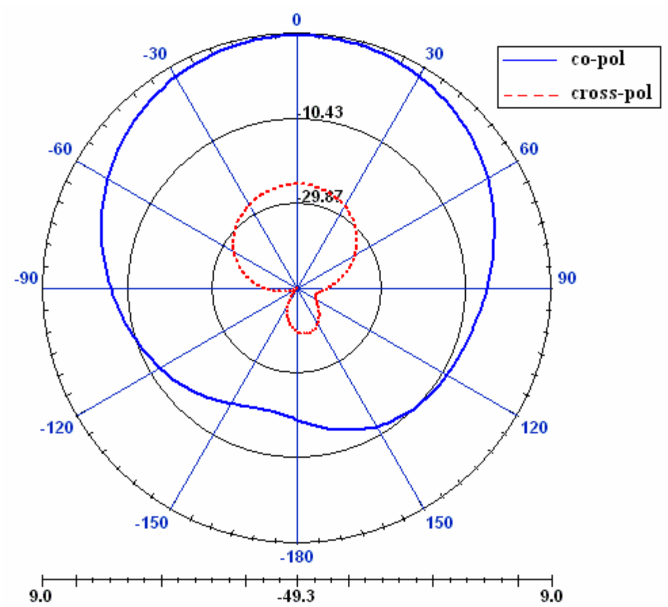

Figure 6. Radiation pattern of the optimized E-shaped patch antenna.

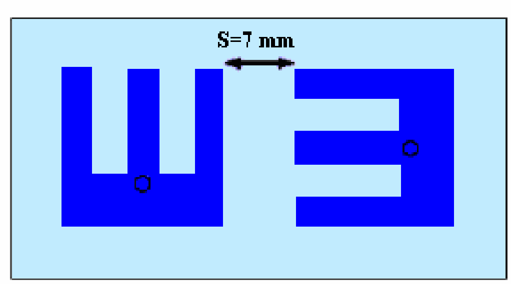

Figure 7. Proposed configuration of two-element E-shaped patch antenna array.

defined as the ratio of the square root of total reflected power divided by the square root of total incident power [26]. The TARC for a lossless N port antenna can be described as

$$\Gamma_a^t = \sqrt{\sum_{i=1}^{N} |b_i|^2} \Big/ \sqrt{\sum_{i=1}^{N} |a_i|^2} \tag{5}$$

where a_i is the incident signal vector with randomly phased elements and b_i is the reflected signal vector. An array's TARC is calculated by applying different combinations of excitation signals to each port.

Table 3. Geometrical parameters of the optimized four element MIMO antennas (Unit: Millimeters).

Parameter	L	W	Ls	Ws	Ps
Two-element MIMO antenna	15.73	14.77	4.97	5.82	2.50

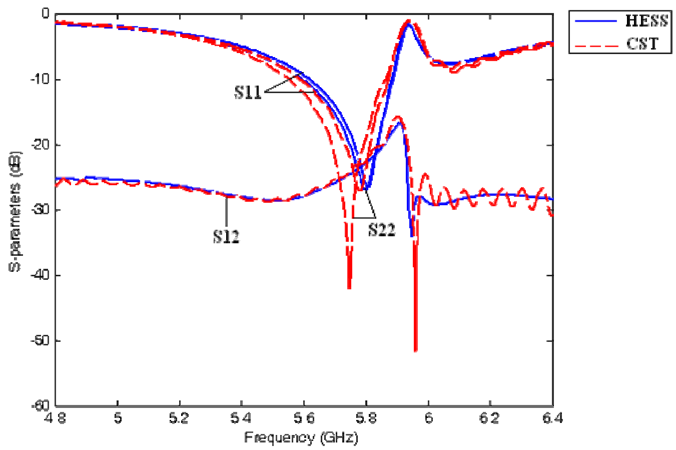

Figure 8. Simulated scattering parameters for the two-element E-shaped patch antenna array.

The optimized geometric parameters obtained are listed in Table 3. Fig. 8 represents the calculated scattering matrix of the two element antenna array. The resulting array has resonant frequencies at 5.8 GHz with bandwidths of 280 MHz and good isolation. Fig. 9 shows the simulated co-polarization and cross-polarization far-field patterns of a MIMO array.

5. FOUR-ELEMENT MIMO ANTENNA

In this section we realize four-element MIMO antenna by using 2-element E-shaped patch antenna arrays as shown in Fig. 10. Fabricated MIMO antenna is shown in Fig. 11. The separation between the edges of the elements is 7 mm and between their centers is 22 mm.

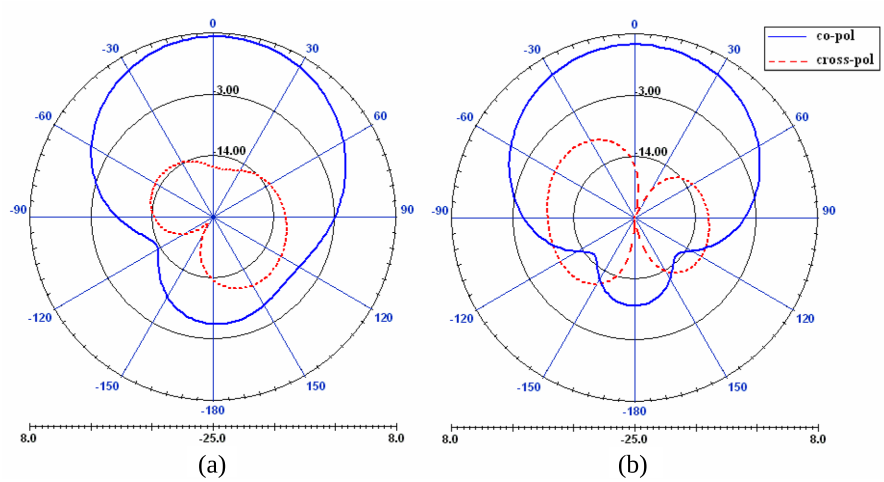

Figure 9. Radiation patterns of the optimized two-element E-shaped antenna array. (a) Port1 is excited. (b) Port2 is excited.

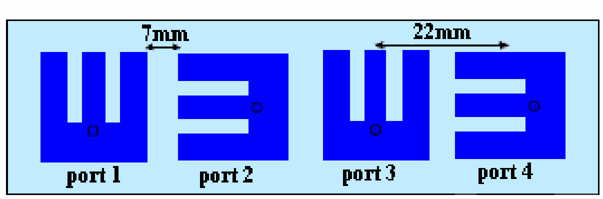

Figure 10. Proposed two different types of four channel MIMO antenna.

As the resonant frequency shifts by adding two more elements, the IWO algorithm is applied to optimize the E-shaped antenna in order to have the best impedance matching at resonant frequency of 5.8 GHz. Also, the fitness function should contain TARC parameter.

Table 4. Optimized geometric parameters.

Parameter	L	W	Ls	Ws	Ps
Four-element MIMO antenna	15.68	13.04	8.08	1.79	2.29

The optimized geometric parameters obtained are listed in Table 4. The first row of the scattering matrix of the four element array is illustrated in Fig. 12. The results at 5.8 GHz are indicative

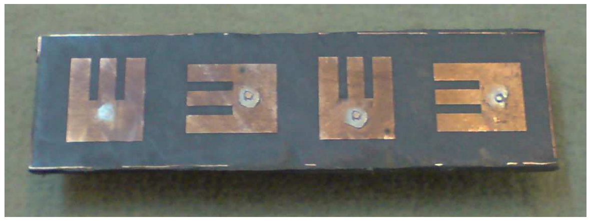

Figure 11. Photograph of the fabricated compact four element MIMO antenna.

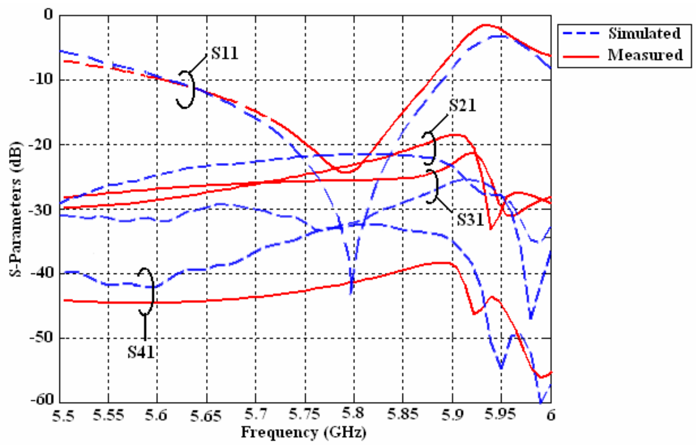

Figure 12. Simulated and measured scattering parameters for the four-element E-shaped patch antenna array.

of an array with excellent return loss and isolation. This figure shows that coupling between each two elements is below −22 dB at 5.8 GHz. Fig. 13 shows the calculated TARC for the two and four element antenna arrays. It is apparent in this figure that at the 5.8 GHz band the TARC value is lower than −25 dB. A comparison of the TARC in two curves shows that TARC dose not change with increase in the number of elements. Due to the low coupling between the elements, a high radiation efficiency (high TARC) is expected at the 5.8 GHz band.

The correlation coefficient is usually calcuated from the 3-dimensional radiation patterns [26]. However, this process requires complex and advanced calculation. Recent studies show that in some cases, such as the uniform random field case, the correlation coefficient

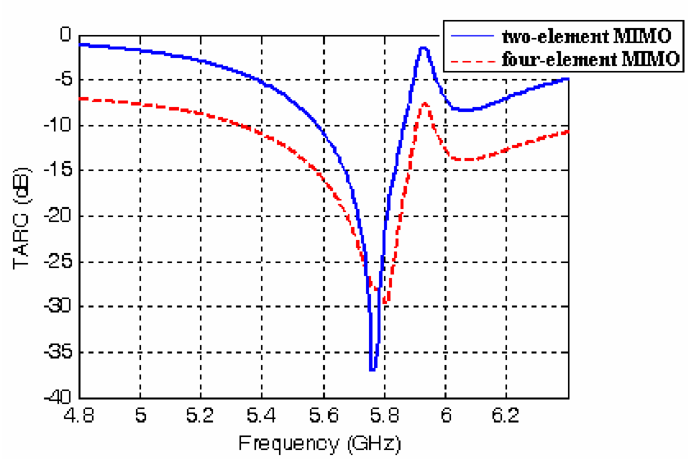

Figure 13. Simulated TARC two and four-element E-shaped patch antenna array.

can be calculated by S-parameters [27]

$$\rho = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|^2}{\left(1 - |S_{11}|^2 - |S_{21}|^2\right)\left(1 - |S_{22}|^2 - |S_{12}|^2\right)}$$

Simulated correlation coefficient of two ports of four-element E-shaped

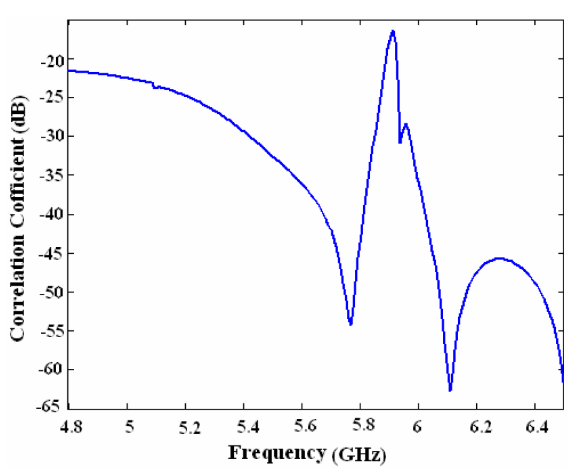

Figure 14. Simulated correlation coefficient of four-element E-shaped patch antenna array.

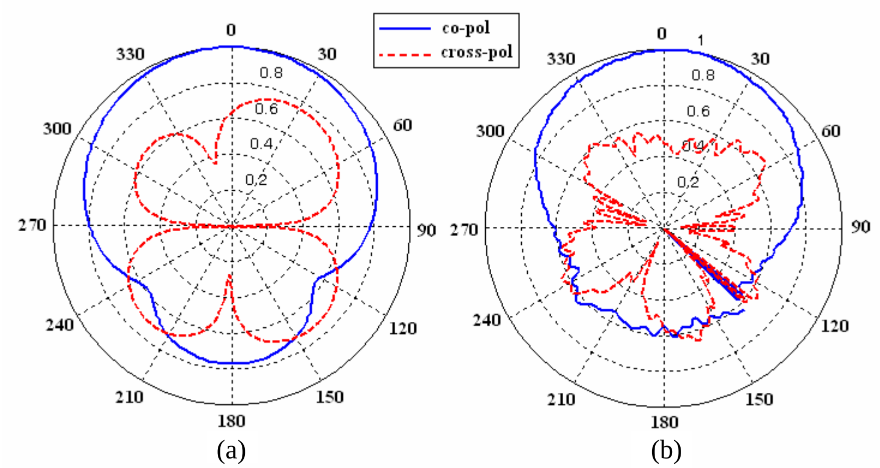

Figure 15. (a) Simulated and (b) measurement Radiation pattern for antenna 1 of the optimized four-element E-shaped patch antenna.

patch antenna array is shown in Fig. 14. Fig. 15 shows the simulated and measured co- and cross-polarization far-field patterns of a MIMO array in x-z plane.

6. CONCLUSIONS

In this paper, a novel Invasive optimization algorithm is applied in MIMO antenna designs. First, the IWO algorithm was tested by designing E-shaped patch antenna. The design criterion was to obtain satisfactory antenna return loss and bandwidth. The procedure and results of the optimizations show that the weed optimizer is able to achieve the optimum design for specified antenna performance in an effective manner. Subsequently the algorithm was utilized to design two-element E-shaped patch antenna array.

The results obtained show that the antenna polarization is more important than the separation distance when the ground size is small and the two antennas are located in the array. The measured results of the optimized four-port E-shaped MIMO antenna agree well with the simulation results. The proposed antenna has low profile, good radiation characteristics and enough wide bandwidth to cover 20 MHz which is required for the WLAN system. This MIMO antennas show about -22 dB mutual coupling in arrays with 0.13λ separation. Although the proposed antenna has good potential for MIMO designs due to its robustness to coupling, its size in comparison to PIFA-like antennas is a drawback for compact MIMO design.

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REFERENCES

1. Foschini, G. J. and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wirel. Pers. Commun.*, Vol. 6, No. 3, 311–335, 1998.
2. Kurosaki, S., Y. Asai, T. Sugiyama, and M. Umehira, "SDM-COFDM scheme using feed forward inter-channel interference canceller for broadband mobile communications," *IEEE 55th Vehicular Technology Conference, VTC2002-Spring*, Vol. 3, 1079–1083, May 2002.
3. Abouda, A. A. and S. G. Häggman, "Effect of mutual coupling capacity of MIMO wireless channels in high SNR scenario," *Progress In Electromagnetics Research*, PIER 65, 27–40, 2006.
4. Stutzman, W. L. and G. A. Thiele, *Antenna Theory and Design*, 2nd edition, Wiley, New York, 1998.
5. Gao, Y., C. C. Chiau, X. Chen, and C. G. Parini, "Modified PIFA and its array for MIMO terminals," *Inst. Elect. Eng. Proc. Microw. Antennas Propag.*, Vol. 152, No. 4, 253–257, Aug. 2005.
6. Gao, Y., C. C. Chiau, X. Chen, and C. G. Parini, "A compact dual-element PIFA array for MIMO terminals," *Loughborough Antennas Propag. Conf.*, Apr. 2005.
7. Gao, Y., X. Chen, Z. Ying, and C. Parini, "Design and performance investigation of a dual-element PIFA array at 2.5 GHz for MIMO terminal," *IEEE Transactions on Antennas and Propogation*, Vol. 55, No. 12, Dec. 2007.
8. Manteghi, M. and Y. Rahmat-Samii, "Novel compact tri-band two-element and four-element MIMO antenna designs," *Proc. IEEE Int. Symp. Antennas Propag.*, 4443–4446, Jul. 2006.
9. Browne, D. W., M. Manteghi, M. P. Fitz, and Y. Rahmat-Samii, "Experiments with compact antenna arrays for MIMO radio communications," *IEEE Transactions on Antennas and Propogation*, Vol. 54, No. 11, Dec. 2006.
10. Honma, N., K. Nishimori, Y. Takatori, A. Ohta, and K. Tsunekawa, "Proposal of compact three-port MIMO antenna employing modified inverted F antenna and notch antennas," *Proc. IEEE Int. Symp. Antennas Propag.*, 2613–2616, Jul. 2006.
11. Chae, S. H., S.-K. Oh, and S.-O. Park, "Analysis of mutual

coupling, correlations, and TARC in WiBro MIMO array antenna," *IEEE Antennas and Wireless Propogation Letters*, Vol. 6, 122–125, 2007.

12. Mehrabian, A. R. and C. Lucas, "A novel numerical optimization algorithm inspired from weed colonization," *Ecological Informatics*, Vol. 1, 355–366, 2006.
13. Rahmat-Samii, Y. and E. M. hielssen, *Electromagnetic Optimization by Genetic Algorithms*, Wiley, 1999.
14. Lu, Y. Q. and J. Y. Li, "Optimization of broadband top-load antenna using micro-genetic algorithm," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 6, 793–801, 2006.
15. Mahanti, G. K., N. Pathak, and P. Mahanti, "Synthesis of thinned linear antenna arrays with fixed sidelobe level using realcoded genetic algorithm," *Progress In Electromagnetics Research*, PIER 75, 319–328, 2007.
16. Mahanti, G. K., A. Chakrabarty, and S. Das, "Phase-only and amplitude-phase only synthesis of dual-beam pattern linear antenna arrays using floating-point genetic algorithms," *Progress In Electromagnetics Research*, PIER 68, 247–259, 2007.
17. Sijher, T. S. and A. A. Kishk, "Antenna modeling by infinitesimal dipoles using genetic algorithms," *Progress In Electromagnetics Research*, PIER 52, 225–254, 2005.
18. Robinson, J. and Y. Rahmat-Samii, "Particle swarm optimization in electromagnetics," *IEEE Transactions on Antennas and Propogation*, Vol. 52, 397–407, 2004.
19. Lee, K. C. and J. Y. Jhang, "Application of particle swarm algorithm to the optimization of unequally spaced antenna arrays," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 14, 2001–2012, 2006.
20. Chen, T. B., Y. L. Dong, Y.-C. Jiao, and F.-S. Zhang, "Synthesizes of circular antenna array using crossed particle swarm optimization algorithm," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 13, 1785–1795, 2006.
21. Boeringer, D. and D. Werner, "Particle swarm optimization versus genetic algorithms for phased array synthesis," *IEEE Transactions on Antennas and Propogation*, Vol. 52, 771–779, 2004.
22. Karaboga, N., K. Guney, and A. Akdagli, "Null steering of linear antenna arrays with use of modified touring ant-colony optimization algorithm," *Wiley Periodicals*, 375–383, 2002.
23. Coleman, C., E. Rothwell, and J. Ross, "Investigation of simulated

annealing, ant-colony optimization, and genetic algorithms for self-structuring antennas," *IEEE Transactions on Antennas and Propogation*, Vol. 52, 1007–1014, Apr. 2004.

24. Mallahzadeh, A. R., H. Oraizi, and Z. Davoodi-Rad, "Application of the invasive weed optimization technique for antenna configurations," *Progress In Electromagnetics Research*, PIER 52, 225–254, 2008.
25. Manteghi, M. and Y. Rahmat-Samii, "Multiport characteristics of a wide-band cavity backed annular patch antenna for multipolarization operations," *IEEE Transactions on Antennas and Propogation*, Vol. 53, 466–474, Jan. 2005.
26. Jesen, M. A. and Y. Rahmat-Samii, "FDTD analysis of PIFA diversity antennas on a hand-held transceiver unit," *IEEE Antennas Propagation, Symposium. Dig.*, 81, June 1993.
27. Blanch, S., J. Romeu, and I. Corbella, "Exact representation of antenna system diversity performance from input parameter description," *IEE Electronics Letters*, Vol. 39, 705–707, May 2003.
28. Blanch, S., J. Romeu, and I. Corbella, "Exact representation of antenna system diversity performance from input parameter description," *IEE Electronics Letters*, Vol. 39, 705–707, May 2003.