Design of a Meander-Shaped MIMO Antenna Using IWO Algorithm for Wireless Applications

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Abstract **─** Using a MIMO antenna system is a well-known technique to enhance the performance of wireless communication systems. In order to create a MIMO antenna system on a wireless device, two or more antenna elements could be placed in a very small space. Thus, the mutual coupling including radiation pattern coupling between closely arrayed antenna elements causes the decrease of a MIMO antenna performance. It means that we must consider not only the antenna size but also the suitable antenna array method to design the MIMO antenna system. The aim of this research was to design an antenna for a four-channel multiple input multiple output (MIMO) system that works at 5.8 GHz with consideration of the mutual coupling. The geometry of the antenna is optimized by using Invasive Weed Optimization algorithm to accomplish high degree of isolation. The measurement and simulation results of reflection coefficient, mutual coupling and radiation pattern are presented and discussed.

Index Terms **─** Antenna, IWO algorithm, MIMO systems.

I. INTRODUCTION

Over the past few years, there has been an increasing worldwide research interest in multiple-input-multiple-output (MIMO) systems, also known as multiple-element antenna (MEA) systems, as they have been shown to have the potential for improved capacity, spectral efficiency and reliability as compared to single-antenna communication systems [1]. MIMO technology is a breakthrough in the field of modern wireless communications, and is poised to play a significant role in the implementation of next generation's wireless products and networks.

In order to study the performance of the MIMO antenna, some parameters need to be considered. Mutual coupling is one of the important factors because higher mutual coupling means lower antenna efficiency [3].

The correlation coefficient between the two antennas is another important parameter since it is associated with the loss of spectral efficiency and degradation of performance of a MIMO system [3]. Correlation of the signals at the different antenna elements can considerably decrease the capacity of a MIMO system [3]. Such correlation occurs particularly for compact MIMO systems, where the separation between the antennas is small; this effect has been investigated extensively. In addition, with a small separation, the effect of mutual coupling between the antennas becomes important. Refs [4]-[8] investigated the impact of this effect on antenna correlation and MIMO capacity.

Total active reflection coefficient (TARC) must also be considered. We use TARC rather than the traditional scattering matrix because the scattering matrix does not accurately characterize the radiation efficiency and bandwidth of an antenna array [9].

This paper, based on spatial diversity, investigates a new low profile four channel MIMO antenna with good isolation and simple fabrication. The antenna element has a meander shape and its dimensions are obtained through the Invasive Weed Optimization, IWO algorithm, [10, 11].

The outline of this paper is as follows. First, is the overview of IWO algorithm, next using this algorithm to optimize the geometry of a meander-shaped patch antenna. After this, four configurations of two element meander-shaped patch MIMO antennas are proposed and the IWO algorithm is applied to each antenna design. In order to study the performance of the MIMO antennas, mutual coupling and total active reflection coefficient are considered. The results of the optimal antenna are presented and discussed. Based on the results, the best type is selected and used to construct a MIMO antenna with four elements.

This four channel MIMO antenna is optimized using the IWO algorithm to achieve acceptable values for the reflection coefficient and isolation. The proposed optimized antenna was fabricated. Measurement results have been compared with simulated results, thus confirming the proposed design methodology.

II. INVASIVE WEED OPTIMIZATION (IWO) ALGORITHM

Invasive Weed Optimization (IWO) is one of the novel numerical stochastic optimization algorithms inspired from colonizing weeds that was first deigned and developed in [10].

Weeds are plants whose vigorous, invasive habits of growth pose serious threats to desirable plants. There are some interesting characteristics in natural behaviors of weeds which have been used in this optimization algorithm, among of those are fast reproduction and distribution, robustness and adaptation to the changes in the environment.

The algorithm can be summarized in the following four steps [10, 12]:

A. Initializing a population

A finite number of seeds composing the initial population are being dispread randomly over the problem space.

B. Reproduction

Every seed that has grown to a new plant is allowed to produce other seeds depending on its fitness. In the simple case, the number of seeds which are produced by each plant increases linearly from the minimum possible number of seeds, corresponding to minimum fitness, to the maximum possible number of seeds, corresponding to maximum fitness in the population as illustrated in Fig. 1.

C. Spatial dispersal

The produced seeds in the previous step are being distributed randomly in the problem space by normal distribution with a mean equal to zero and a variance parameter decreasing over time. By setting the mean parameter equal to zero, the seeds are distributed randomly such that they locate near to the parent plant. As the variance decreases over time, the fitter plants are grouped together and inappropriate plants are eliminated over time. The standard deviation (SD) that is the root square of the variance of this distribution is calculated in every step as shown in equation (1):

$$\sigma_{iter} = \frac{(iter_{\max} - iter)^n}{iter_{\max}^n}(\sigma_{initial} - \sigma_{final}) + \sigma_{final}, \quad (1)$$

where σ_{init} and σ_{final} are the initial and final values of SD for the normal distribution respectively. $iter_{max}$ is the maximum number of iterations before stopping the algorithm, σ_{iter} is the SD at the present step and, n is the nonlinear modulation index usually set to 3.

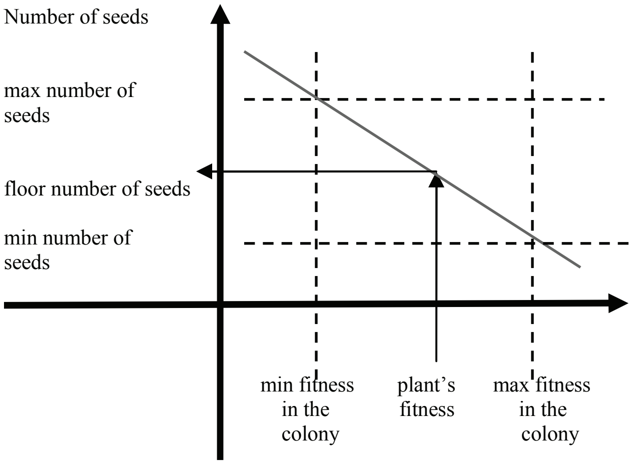


Fig. 1. Seed production procedure in a colony [10] (lower fitness means better situation).

D. Competitive exclusion

After some iteration, the number of plants in a colony will reach its maximum (p_{max}) by fast reproduction. However, it is expected that the fitter plants to have been reported to be more than the undesirable ones. Thus, the final step is to eliminate the inappropriate and weaker plants in a competitive manner for limiting the maximum number of plants in a colony. The process continues until the maximum number of iterations is reached and the plant with the best fitness is selected as the optimal solution.

III. IWO OPTIMIZATION OF THE SINGLE MEANDER-SHAPED PATCH ANTENNA

The structure of the antenna is described in Fig. 2. The antenna is fed by a 50Ω coaxial probe through an SMA connector. The meander-shaped patch antenna is etched on a 3.2-mm-thick Rogers RT/duroid5880 and mounted over a 25 mm × 25 mm metal ground plane. The IWO algorithm is then applied to optimize the meander-shaped antenna in order to have the best impedance matching at resonant frequency of 5.8 GHz.

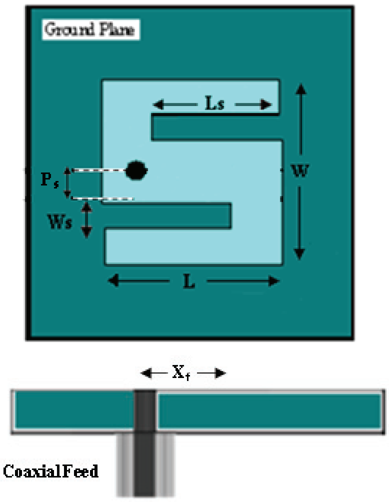


Fig. 2. Configuration of a meander-shaped patch antenna.

At the first step we should choose the parameters which need to be optimized. Through processing these parameters, by modifying and changing them within a reasonable range, we search for the optimal solution. To have these done, minimum and maximum values for each dimension in a 6-dimensional optimization should be determined. This is referred to as L_{ini}. Then a good function must be selected that accurately represents, in a single number, the goodness of the solution. In this problem, the shape of the meander-patch is the solution and as shown in Fig. 2, the geometrical parameters to be optimized include: the patch length L, the patch width W, the slots length Ls, the slots width Ws, the position of feed point X_f and the position of slots P_s.

As such, the dimension of the solution space is six. For the single meander-shaped patch antenna, the return loss at the desired frequencies is optimized using $f = \max\left(\left|S_{11}\right|, \text{ at } f = 5.8\text{ GHz}\right)$.

Table 1 specifies the IWO algorithm setup for minimization of this function. To maintain the meander-shaped structure, the following conditions must also be held as the additional geometrical restrictions:

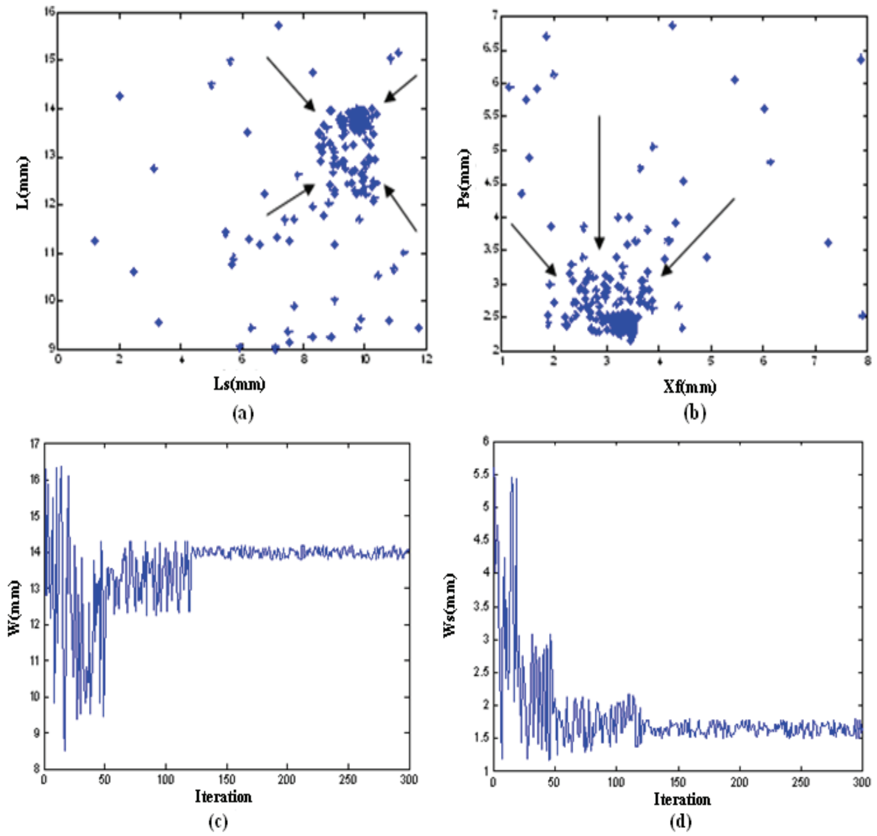
$L_s < L$ The slots cannot go beyond the patch.
$W_s + P_s < W/2$ The top and bottom stubs must exit.
$X_f < L/2$ The feed cannot cross the patch.

Table 1: IWO parameters values for the meander-shaped patch antenna.

Symbol	Quantity	Value
NO	number of the initial population	10
I*tmax*	maximum number of iterations	300
Dim	problem dimension	6
P_{max}	maximum number of plant population	15
S_{max}	maximum number of seeds	5
S_{min}	minimum number of seeds	1
n	nonlinear modulation index	3
σ_{initil}	initial value of the standard deviation	3
σ_{final}	final value of the standard deviation	.001

Table 2: Geometrical parameters of the optimized meander-patch antenna (Unit: Millimeters).

Parameter	L	W	Ls	Ws	ps	xf
Value	13.45	14.21	9.55	1.81	2.35	3.33



(a)
(b)
(c)
(d)

Fig. 3. Convergence results of the meander -shaped patch antenna designs. (a) Conversion of length and length of slots of the patch. (b) Conversion of position of the slots and the feed point(c) Variations of the width of the patch versus iteration number (d) Variations of the width of the slots versus iteration number.

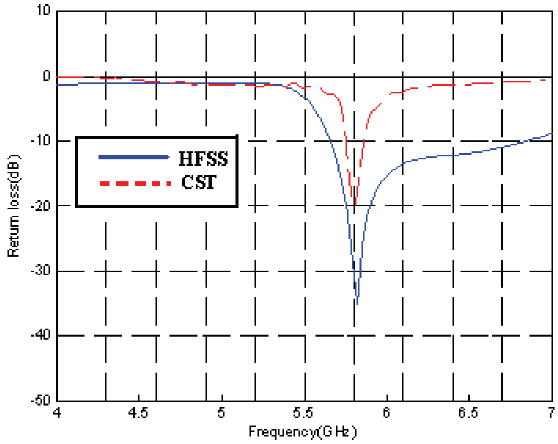


Fig. 4. Simulated S_{11} curves of the optimized meander-shaped antenna.

The optimized results of the single meander shape antenna are presented in Table 2. Figure 3 illustrate the convergence results of the optimization. Figure 4 shows the simulated return loss (S_{11}) curve, using CST and HFSS software's. As can be seen from this figure, the antenna resonates at 5.8 GHz, so the goal of optimization has been satisfied. Radiation pattern of the optimized meander-shaped patch antenna is plotted in Fig. 5.

The total time of the design process is about 12 hours on a Pentium IV (2.8 GHz) machine.

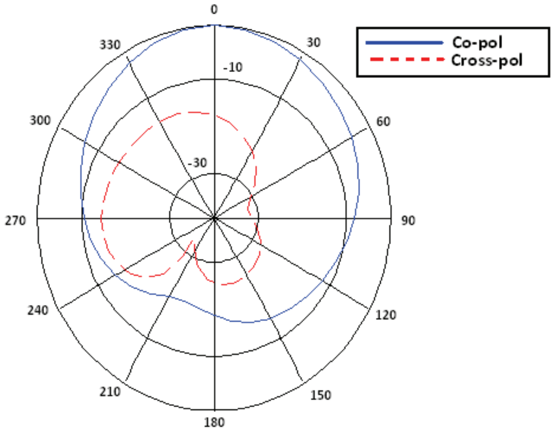


Fig. 5. Radiation pattern of the optimized meander-shaped patch antenna.

IV. TWO-ELEMENT MEANDER-SHAPED PATCH ANTENNA

Since the meander-shaped patch antenna is not influenced by another nearby meander antenna, it is an ideal candidate for use in compact array designs. In this research, four different antenna array configurations, as shown in Fig. 6, each using two antenna elements of Fig. 1 are proposed. The meander antenna array elements are separated by 7mm (0.13 λ).

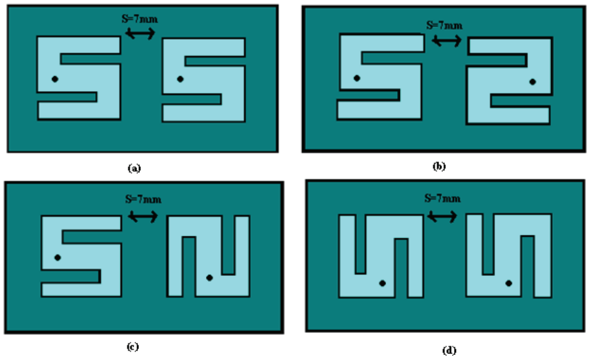


Fig. 6. Four different configurations of dual antenna arrays. Type: (a) 1, (b) 2, (c) 3, (d) 4.

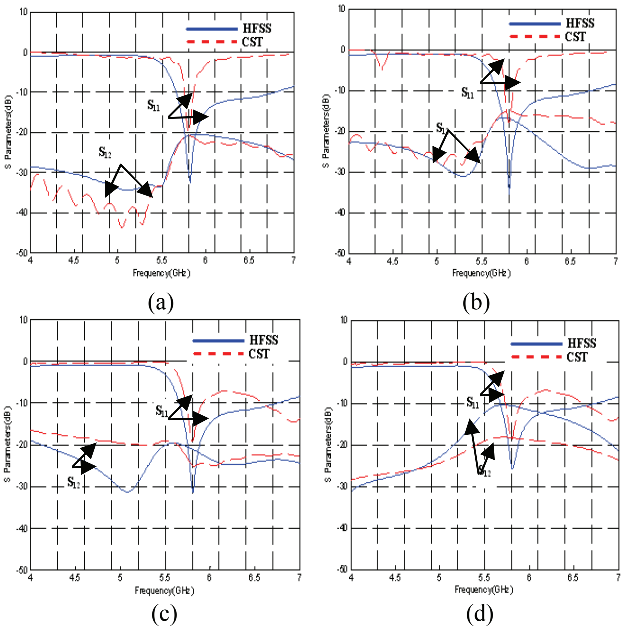
Now the IWO algorithm is used to optimize the geometry of the antenna in order to improve the isolation between antenna ports, the fitness function for this optimization should contain mutual coupling between array elements.

The mutual coupling between the antennas is obtained from S_{ij} of the scattering matrix. As the scattering matrix does not accurately characterize the radiation efficiency and bandwidth of a MIMO antenna [13], the array's Total Active Reflection coefficient (TARC) is used to account for both coupling and random signal combination.

TARC is defined as the ratio of the square root of total reflected power divided by the square root of total incident power [14]. The TARC for a lossless N port antenna can be described as:

$$\Gamma_a^t = \sqrt{\sum_{i=1}^{N} |b_i|^2} \Big/ \sqrt{\sum_{i=1}^{N} |a_i|^2} \;, \qquad (2)$$

where a_i is the incident signal vector with randomly phased elements and b_i is the reflected signal vector. By applying different combinations of excitation signals to each port the array's TARC is calculated. The simulated scattering matrix of the two element arrays is presented in Fig .7. The resonant frequencies of these arrays are at 5.8 GHz with a -10 dB bandwidths of 900 MHz. As can be seen from this figure, the return loss of all the four types are good but the isolation is high only for type 1, therefore antenna types 2,3 and 4 aren't suitable for MIMO application. Figure 8 shows the simulated co-polarization and cross-polarization far-field patterns of a MIMO array.



(a) (b)

(c) (d)

Fig. 7. Simulated scattering parameters for the two-element meander-shaped patch antenna array, Type: (a) 1, (b) 2, (c) 3, (d) 4.

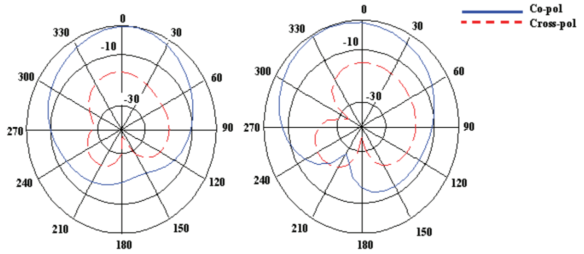


Fig. 8. Radiation patterns of the optimized two-element meander-shaped antenna array. (a) Port1 is excited. (b) Port2 is excited.

V. FOUR-ELEMENT MIMO ANTENNA

In this section a four-element MIMO antenna, using the type (1) 2-element meander-shaped patch antenna array, is discussed (Fig. 9). A prototype antenna (Fig. 10) has been made and measured. The edge to edge element spacing is 7 mm. Table 3 shows the optimized geometric parameters for this array.

Figure 11 depicts the first row of the scattering matrix of the four element array. As can be seen in this figure coupling between each two elements is below -20dB. Figure 12 shows the simulated TARC for the two and four element antenna arrays and one can see from this figure that the value of this parameter is lower than -30dB at the 5.8GHz frequency.

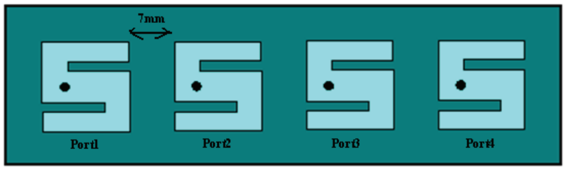


Fig. 9. the proposed four channel MIMO antenna.

Table 3: Geometrical parameters of the optimized four channel MIMO antenna (Unit: Millimeters).

Parameter	L	W	Ls	Ws	ps	xf
value	13.78	13.98	9.81	1.64	2.41	3.39

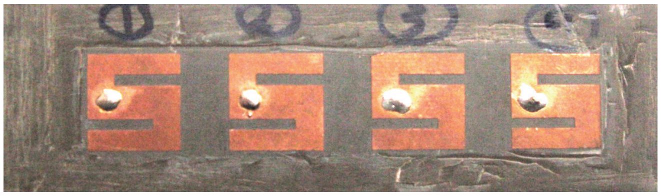


Fig.10. Photograph of the fabricated compact four element MIMO antenna.

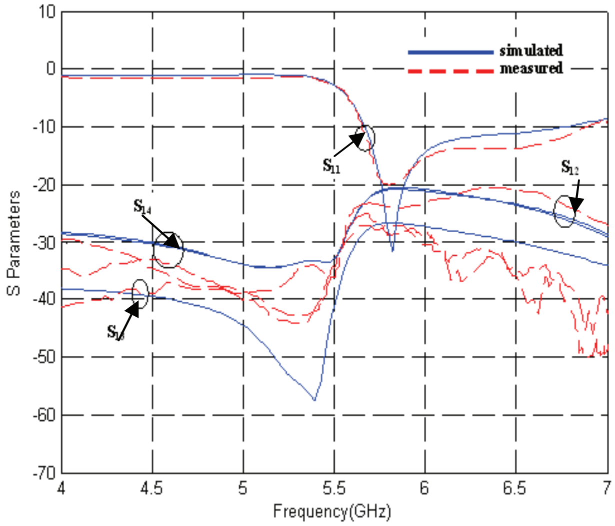


Fig. 11. Simulated and measured scattering parameters for the four-element meander-shaped patch antenna array.

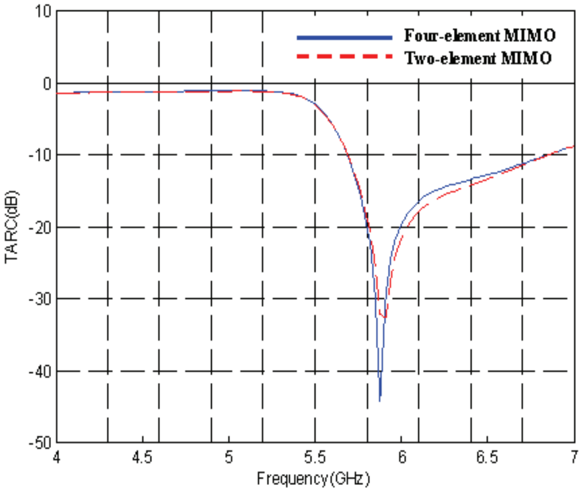


Fig. 12. Simulated TARC of two and four-element meander-shaped patch antenna arrays.

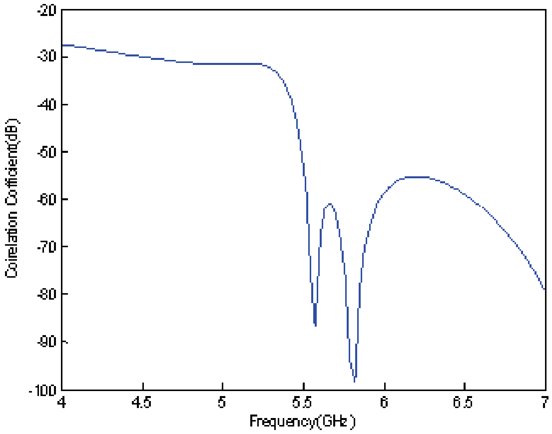
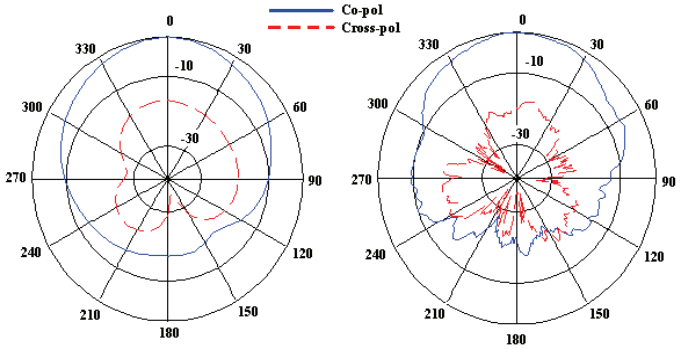


Fig. 13. Simulated correlation coefficient of four-element meander-shaped patch antenna array.

As shown in [16] in cases such as a uniform random field case the correlation coefficient can be calculated by S-parameters instead of using 3-dimensional radiation patterns [15].

$$\rho_c = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|^2}{\left(1-|S_{11}|^2-|S_{21}|^2\right)\left(1-|S_{22}|^2-|S_{12}|^2\right)} . \quad (3)$$

Simulated correlation coefficient of two ports of the four-element meander-shaped patch antenna array is presented in Fig. 13.



(a) (b)

Fig. 14. (a) Simulated and (b) measured radiation pattern of the optimized four-element Meander-shaped patch antenna array (port1 excited).

The measured and simulated co- and cross-polarization far-field patterns of the optimized MIMO antenna at a resonant frequency of 5.8 GHz in the x-z plane are plotted in Fig. 14. The measured pattern is in good agreement with the simulated pattern.

VI. CONCLUSION

In this paper, Invasive Weed Optimization algorithm is applied to meander-shaped patch antenna designs. The mentioned algorithm was used to optimize meander-shaped patch antennas, considering return loss and bandwidth as design criteria. The procedure and results of this technique show that the weed optimizer is able to achieve the optimum design for a specified antenna performance in an effective manner. Subsequently the algorithm was utilized to design two-element meander-shaped patch antenna arrays. The measured results of the optimized four-port meander-shaped MIMO antenna agree well with the simulation results. The proposed antenna has low profile, good radiation characteristics and sufficiently wide bandwidth to cover 20MHz which is required for the WLAN system. This MIMO antennas show about 20 dB mutual coupling in arrays with 0.13 λ separation.

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