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ORIGINAL ARTICLE

Asymetric Feedline Bandwidth Enhancement Approach for Broadband Microstrip Antenna

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ABSTRACT

A simple Particle Swarm Optimization (PSO) variant is developed specifically for microstrip antennae and is used to study the Asymmetric Feedline technique. In an edge-fed Microstrip antenna, there is usually a Microstrip feedline that extends from the edge to the radiating patch. Convential wisdom is to use a symmetric feedline. This paper proposes that breaking the symmetry leads to better impedance matching over wider bands. A conventionally designed broadband new rectangular microstrip patch antenna with cut corners and partial ground plane is optimized using PSO. Traditional approach implies designing an initial structure using known equations for similar structures. Then trial-and-error method is applied to countless geometric dimensional permutations one by one. The presented variant of PSO is built with a bias for antenna design. The algorithm is implemented using Matlab for the PSO computations. It uses Zeland IE3D for simulation and fitness evaluation. For the patch antenna, a significant bandwidth improvement is achieved and the overall antenna dimensions are kept practically same.

Key words: *PSO, microstrip antenna, asymmetric feedline, optimization.*

Introduction

Particle Swarm Optimization, or PSO, was first discussed by the authors in (Kennedy, J. and R. Eberhart, 1995). Its popularity has continuously grown ever since. Various practical applications have been conceived since the algorithm's inception, including but not limited to antenna design (Robinson, J. and Y. Rahmat-Samii, 2004). In (Robinson, J. and Y. Rahmat-Samii, 2004), an extensive study of PSO is carried out various benchmark functions and problems. It illustrates the handling of particles flying out of the search space. It shows the 'invisible wall technique' to be the best of the lot but fails to explain why. In this study, some underlying assumptions were made about the 'walls', from which a hybrid implementation was perceived. Wireless communication is considered one of the booming industries across the globe (Islam, M.T., 2009). It hence faces various tough challenges including meeting demands for added functionalities. These require the use of higher data rates and larger bandwidths. Microstrip antennae have a low profile and are compact enough to be placed on portable communication devices (Azim, R., 2011; Liu, L., 2011; Azim, R., 2011; Azim, R., 2011; Faruque, M.R.I., 2011; Azim, R., 2011; Shakib, M.N., 2010; Faruque, M.R.I., 2010; Mobashsher, A.T., 2010; Faruque, M.R.I., 2010; Azim, R., 2010; Islam, M.T., 2010; Islam, M.T., 2009; Islam, M.T., 2009). They are easy to integrate with microwave circuits and are simple to fabricate and mass produce. Microstrip antennae suffer from inherent drawbacks of low gain and narrow bandwidth. It may thus be inferred as an optimization problem. This paper establishes a framework for optimizing the return loss bandwidth of a patch antenna using a heuristic algorithm known as Particle Swarm Optimization (PSO). Use of heuristic algorithms in antenna design has recently received much attention. Application of such algorithms seems like a logical successor of intelligent trial and error design techniques used conventionally. PSO automates the development and optimization process, hence drastically decreasing human interaction. It practically makes no assumptions about the antenna or its properties (Moushuo, W., 2011). While the underlying phenomena of patch antenna are understood, it is hard to extend them to complex geometric shapes and parametric analyses. Often it is too hard to be considered computationally feasible. Further, antenna designs often face minimal criteria that they are required to meet rather than one single optimal design consideration. PSO cannot guarantee finding the optimal design. However it is good at finding sub-optimal designs that can meet the desired criteria. These features establish that PSO is intrinsically suited for antenna design.

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Particle Swarm Optimization:

A. Analogy and PSO Terminology:

PSO was pioneered by Kennedy and Eberhart in 1995. It was developed from the foraging behavior of bees in a garden looking for nectar. PSO uses particles, bees in our analogy, to represent candidate solutions. As the particles fly though the solution space, i.e. 'the garden', PSO stochastically updates the flight path. The update depends on three factors which are termed inertia, cognitive and social. Inertia models the particles tendency to follow its current flight path. Cognitive portion stores the particle's best performance and its location. The cognitive influence drives the particle towards that very local best or personal best. Third influence works almost identically as the cognitive, except global best, or swarm best, is used rather than the local best. This mimics the cooperative nature of a swarm of bees. We assume that there was complete and perfect information exchange between particles at all times. The equations used to describe PSO are shown below.

$$v_{i+1} = wv_i + c_1 r_1 + (d_{local\ best} - d_i) + c_2 r_2 \left(d_{global\ best} - d_i\right) \quad (1)$$

$$d_{i+1} = d_i + v_{i+1} \quad (2)$$

Where v_i is the velocity of a particle at i^{th} iteration, d_i is the vector containing dimensions of a particle at i^{th} iteration, w is the inertia coefficient, r_1, r_2 are the random values between zero and unity and c_1, c_2 are the cognitive and social coefficients respectively.

Equation (1) shows how the momentary velocity of each bee is modified and Eq. (2) how velocity is used to update the position of the bees. Now, the variables w, c_1 and c_2 are constants that determine the nature of the search. Choice of values for them is hotly debated and considered by most to be application specific.

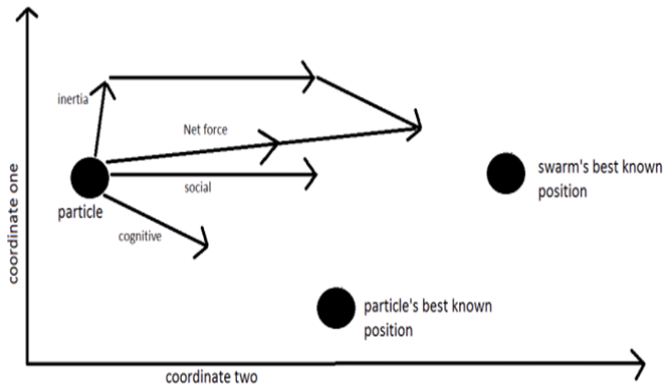

Fig. 1: Breakdown of the PSO components.

Figure 1 illustrates the effect of each component of PSO on a particle's velocity. We need to understand that the only way to be sure that the solution to a function found by any optimization algorithm is the global optimum is by carrying out an exhaustive study of the entire search space. This is often, if not always, computationally unfeasible. Hence PSO offers an approach to reduce computation by sacrificing the 'quality' of the solution.

B. Modifications to Classical PSO:

In this paper, the PSO was tweaked for the problem at hand. Industry requirements push for more multifunctional and miniature sized antennae. This was accounted for by considering any solution that resulted in an antenna that is larger than the original to be a non-feasible solution. Their performances were not evaluated and fitness was considered zero. This work deals with a maximization problem (maximum bandwidth achievable). The bandwidth has to be non-negative. Hence applying zero for non-feasible solutions is an elegant workaround to this particular problem. This is the invisible wall strategy.

On the other extreme, if a dimension becomes negative as allowed by Equations(1) and (2), it results in a non-feasible shape and actually cannot be simulated properly or meaningfully. Hence another novel tactic is devised for this problem. The violating dimension is set to zero, making the design feasible. This is the absorbing wall strategy. These violation handling techniques ensure reduced computation and a more thorough search for 'better' antennae which are definitely smaller than the original design.

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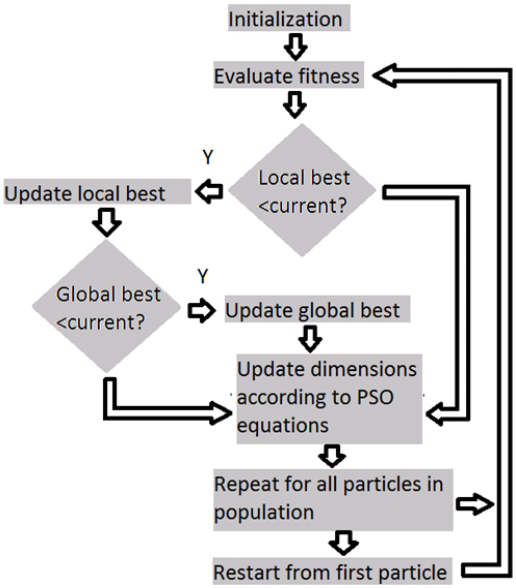

Fig. 2: Flowchart for Classical PSO.

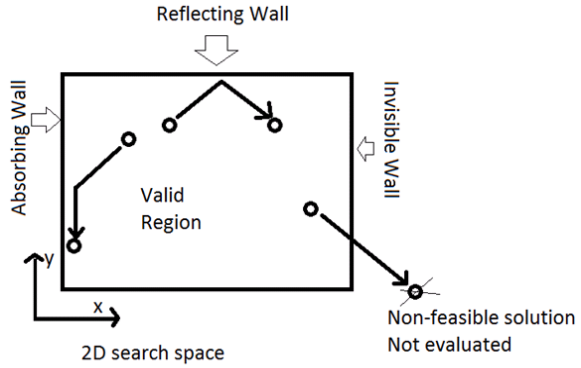

Fig. 3: Illustration of different types of 'Walls'.

Next we delve into the fitness function. The fitness function was equated to just the -10dB return loss bandwidth, as per industry requirements, with only one penalty co-efficient as shown in Eq. (3). The penalty coefficient is considered unity when lower edge of the bandwidth would be 3.15 GHz. The value was chosen to ensure that the WiMAX bands would be covered. If violated, the penalty coefficient becomes 10, hence reducing fitness drastically. The fitness equation is as follows:

$$Fitness = \frac{Bandwidth_{-14dB}}{\alpha} \tag{3.a}$$

$$Where\ \alpha = \begin{cases} 1 & Lower\ edge < 3.15 \\ 10 & Lower\ edge \geq 3.15 \end{cases} \tag{3.b}$$

The population is usually generated randomly in most PSO problems. In this case that would hardly be a fair starting point. This study started with an antenna design that was optimized using conventional means. A population of 30 antennae was generated from the original design by making random modifications to their dimensions as per the equation below. This might be considered one iteration of simulated annealing at infinitely high temperature. These random modifications, or mutations, are at most 20%, determined by '*a*', of the original dimension. '*d*' is an array containing all optimization dimensions of an antenna. One antenna in the population is kept same as the original design as there is no sense in 'reinventing the wheel'.

$$d = (1 - ar)d_{initial} \tag{4}$$

Finally the PSO process applies a process of varying the acceleration coefficients, namely the inertia coefficient. Study show that decreasing inertia results in faster convergence (van den Bergh, F., 2002). The author

of (van den Bergh, F., 2002) shared various strategy for coefficient variation. This study uses a simple technique for the modification. Initially w = 0.9 is considered. After a non-definite number of iterations when the performance of the antenna is deemed to have improved sufficiently, w is reduced to 0.2, hence allowing quick convergence. Allowing a final rapid convergence, rather than using a termination criterion, allows a final bout of local exploration around the best result. This ensures that local optima are reached.

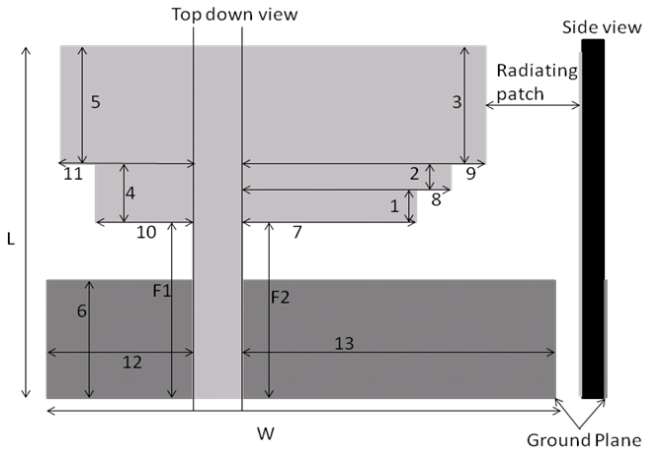

Fig. 4: Antenna dimensions to be optimized.

Table 1: Dimensions before and after optimization.

Dimension	Initial value(mm)	Optimized value(mm)
1	2.5	1.867
2	2	1.811
3	10	9.959
4	3	2.446
5	11.5	12.614
6	5.5	4.932
7	8.125	5.883
8	10.125	7.13
9	12.125	8.066
10	2.62	2.96
11	4.62	4.52
12	6.37	6.762
13	19.87	19.476

C. The Initial Design and Search Space:

The initial design, shown in Fig. 4, is used to define the search space. The antenna is a rectangular patch with cut corners and partial ground plane. Its overall dimensions, *L* and *W*, were considered boundaries of the search space. An imaginary cuboid was drawn around the initial design so that the cuboid was barely big enough to contain the antenna. If a potential design resulting from the PSO algorithm would protrude out of the cuboid, the design would be deemed invalid. It would not be simulated and its fitness would be considered zero. Hence any antenna design spat out by the algorithm would definitely be equal or smaller in size than the original.

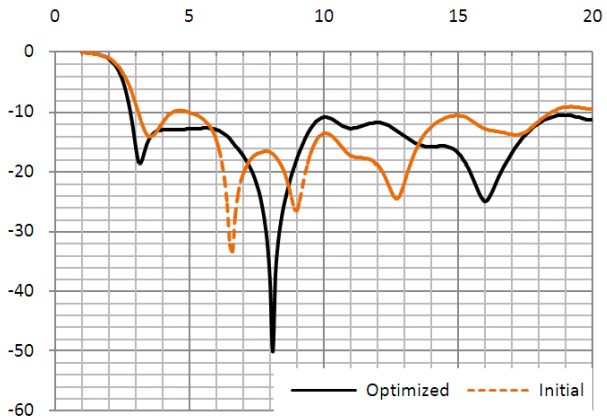

Fig. 5: Return loss profile of antenna before and after optimization.

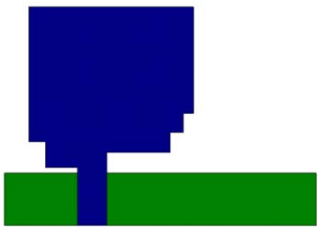

Fig. 6: Optimized design.

This study is geared towards a thorough, rather than quick, traversing of the search space. 'No free lunch' (NFL) states that a search algorithm needs to be exhaustive to be certain of the solution being optimal. Hence the termination criteria strategy, when applied to antenna design, appears a bit unnatural. Thus the selection of acceleration coefficients is geared towards exploration rather than convergence. A word of caution needs to be heeded. The choice these coefficients is simply application specific, hence requiring recalibration for each antenna.

The feedline is symmetric when dimensions F1 and F2 are equal, as in the initial design. The algorithm sees them as separate dimensions and is allowed to alter them. In the optimized design, they are not equal. The asymmetric configuration should, in theory lend itself to enhance the return loss bandwidth.

The search space is 13-dimensional with each dimension being non-negative and having a maximum positive value set by the initial design. The dimensions considered for optimization are illustrated in Fig. 4 with the dimension number next to it. F1 and F2 were not put up for optimization. Instead they were passively varied by altering dimensions 1-5, while holding L constant. The number of dimensions drastically affects the complexity of the optimization performance. The optimization dimensions and their values, before and after optimization, are listed in Table I.

Results and Discussion

The return loss profile as depicted in Fig.5 shows the removal of the two 'notches' at 4.5 GHz and 19 GHz. Apart from the other dimensional changes, the asymmetric changes to the feedline help attain this significant increase in bandwidth by notch removal. The choice of wall type needs to be considered carefully as they each have their advantages. The absorbing wall ensures a thorough search at the wall. The value is reset to a specific minimum if exceeded, hence the minimum value will feature is most iterations and population members. The invisible wall reduces computational complexity by decreasing the number of simulations that need to be run. Its advantage over reflecting wall is little understood. Invisible wall does not create abrupt changes to the flight path of the particles hence seeming more congruent with the analogy of bees, while allowing reduced computation.

Finally, the use of absorbing walls ensured a thorough search for smaller antennae. Though this does not guarantee the finding of a smaller design, it does increase the likelihood of doing so. Fig. 6 depicts the optimized design

Conclusion and Recommendations:

Asymmetric feedlines can be a useful impedence matching tool. Its implementation is still difficult owing to lack of known equations. PSO can handle the asymmetry with ease. PSO is quite a compact and robust tool for antenna design and optimization. This study illustrates how conceptual considerations can be incorporated into a PSO algorithm. The use of different walls yields an interesting avenue of study. Their combinations may be used to create countless possibilities and a study needs to be conducted to form guidelines in picking the correct combination for a particular problem. When compared to conventional optimization, PSO is far less tedious. It needs only recalibration for new antennae. With ever decreasing cost of processing, PSO may be used in better and bolder ways to optimize antenna design in the future.

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