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Using polygonal defect in ground structure to reduce mutual coupling in microstrip array antenna

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The surface wave propagation is a significant problem in designing microstrip array antennas that causes the mutual coupling between array elements. There are several methods to suppress this effect and decrease the propagation of surface waves,such as using defected ground structures (DGS). Determining the shape of DGS is the main difficulty when using these structures. In this paper,a new method is proposed to be used in designing array antennas in which the slot shape of DGS in the ground plane of the antenna is assumed to be a polygon, and its shape is obtained by using the enhanced genetic algorithm (GA) and ant colony optimization (ACO). In this case, an array antenna with two elements is designed to work in 9.5 GHz and the gain, return loss and mutual coupling of this antenna is optimized. Finally, the design procedure is verified by simulation and measurement.

Keywords: ant colony optimization; defected ground structure; genetic algorithm; microstrip array antenna; mutual coupling; polygonal defected ground structure

Introduction

Microstrip antennas are widely used due to their advantages such as small size, low cost, light weight, simple manufacturing, and their compatibility with integrated circuits.[1] On the other hand, there are some problems with microstrip antennas such as narrow bandwidth, low radiation power and surface wave excitation.[2,3] Microstrip antennas can be used to form array antennas, but in this case, excitation of the surface waves is a significant problem and leads to mutual coupling in array antennas.

The coupling between array antenna elements can be caused by the near-field, far-field and surface waves, and some techniques are presented to suppress each of these couplings.[4–11] The near-field coupling can be effectively deceased by increasing the separation between the array elements. But the space increment between the elements has insignificant effect on the surface waves coupling. The far-field coupling can be decreased by changing the patch shape of elements.[5] In the literatures, the surface waves are suppressed by using band-gap structures,[10] cutting substrate between the patches, using compensating pins [11] and defected ground structures (DGS).[12–16]

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Using DGS is a common solution to suppress the propagation of surface waves and help to decrease the mutual coupling effect in array antennas. The DGS method has the simplest fabrication procedure compared with the other method to cancel surface waves. DGS is created by cutting a section of the ground plane in array antenna; therefore the current distribution in the ground plane of the antenna is disturbed. In this case, by changing the shape and position of the DGS, the excitation and propagation of electromagnetic waves in the substrate layer can be controlled. Many of DGS shapes have been studied such as concentric circle,[12] spiral,[13] Wang-shaped [14] and dumbbells.[15] Each DGS shape can be represented as an equivalent circuit consisting of inductance and capacitance, which leads to a certain frequency band-gap determined by the shape, dimension and position of the defect. DGS gives an extra degree of freedom in microwave circuit design and can be used for a wide range of applications, such as filters, couplers, dividers and microstrip antennas. Also, DGS can be used in array antennas to reduce the mutual coupling. For example, in [16], it is shown how DGS can be applied to reduce the mutual coupling between array elements and eliminate the scan blindness in a microstrip phased array antenna.

Sometimes, the simple shapes for DGS which are presented in the literatures have some disadvantages. For example, in [13] the mutual coupling has been reduced, but the DGS have destroyed the gain of the antenna array. In this paper, a new method is proposed in which the DGS is assumed to be a polygonal slot and its shape, size and position is obtained by the enhanced genetic algorithm (GA) and enhanced ant colony optimization (ACO).[17] The advantage of this method is that the different parameters of array antenna, such as mutual coupling, return loss, gain and so on can be optimized together.

In this section, an array antenna with two microstrip rectangular patch is designed to work in 9.5 GHz. The antenna structure consists of two substrates and three conductive layers. The conductive layers are finite ground plane, feed line layer and patch layer. The thickness and dielectric constant of both substrate layers are equal and the same. The thickness is 0.762 mm, and the relative dielectric constant is 3.38. As the array antenna is designed to work in 9.5 GHz, so the dimensions of the patches are 10 and 7.5 mm and the side to side distance between them is assumed to be 5 mm which is about $\lambda_0/6$. This distance is very small, and the patches are very near together. In this situation the surface waves are at high level, and the mutual coupling is very significant. So the performance of the proposed method is better investigated. Also, the dimensions of the ground plane are 43.5 and 40 mm. The patches are fed by proximity coupling method. The array antenna structure and its side view are shown in Figure 1.

Design procedure

The slot shape of the DGS is considered as a non-regular polygon.[18] The number of polygon vertices depends on the application needs. In this paper, the slot shape of the DGS is assumed to be a polygon with nine vertices. To have a straight radiation pattern, currents should be symmetric in the ground plane. Therefore, the shapes of the DGSs are assumed to be the same and they are mirror of each other. On the other hand, this symmetry property significantly decreases the simulation time and speed up the design procedure. The design procedure goal is to find the optimum shape for the DGS to have an array antenna with proper gain and least amount of return loss and mutual coupling. In the GA, at first, a random population is generated, and the fitness of each member, which is an array antenna, is calculated by the FEKO simulator,[19] which is based on the method of moments (MOM). The fitness of each array antenna

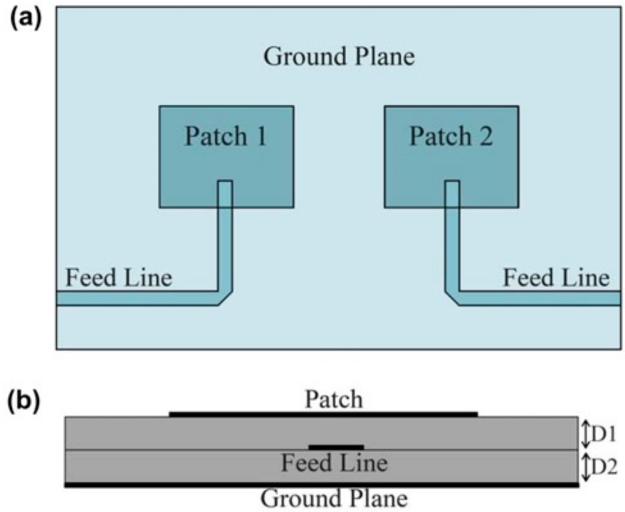

Figure 1. (a) Array antenna structure and (b) its layer structure.

is a function of its reflection coefficient, mutual coupling and gain and the best fitness value is occurring for the least amount of reflection coefficient and mutual coupling and gain value greater than 10 dB. The members with better fitness mate together and generate next population. The GA stops when the optimal array antenna with desirable properties is found.

The shapes of the slots in the ground plane are determined by the positions of their vertexes, so the x and y values of the vertices are the parameters that must be optimized during the optimization process. It should be noted that the x and y values of the vertexes can vary without any constraints. Therefore, if they are connected in a wrong way, an invalid shape that its sides intersect each other will be created, as illustrated in Figure 2.

To solve this problem, enhanced ACO is used. In this case, the connections between the vertexes of a typical polygonal are processed with enhanced ACO and the right connections are found. To do this, some artificial ants are generated and randomly placed on vertexes. Ants move from one vertex to another randomly and deposit trail of pheromone on their path. The ants' goal is to find the path between all the vertexes without any intersection along the path. In many cases, the shortest path is the one without any intersection, and therefore, finding the shortest path can be helpful to find the path without intersection. Movement of the ants between the vertexes should satisfy the simple rules below:

- Each ant moves only once through each vertex.
- Each ant must travel through all vertexes.
- Ant deposits more pheromone on shorter paths.
- Ant deposits less pheromone on the paths that have intersection with travelled paths.
- Ant prefers to travel through the path with more pheromone.

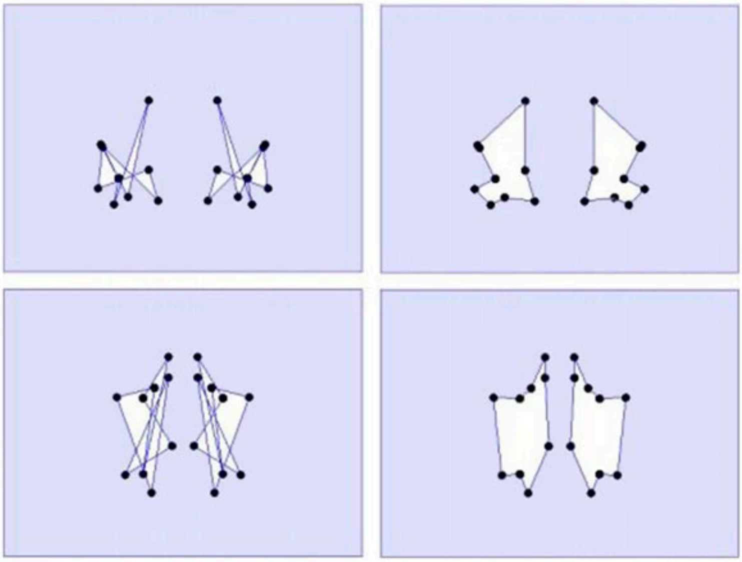

Figure 2. Typical invalid DGS shape (left column) and validated ones (right column).

Some invalid DGS slot shapes and invalided ones are illustrated in Figure 2. Moreover, a flowchart that describes the method is shown in Figure 3.

The GA and ACO codes are written in MATLAB software.[20] Figure 4 shows the optimal array antenna that is obtained by the proposed design method. The reflection coefficient and mutual coupling of the array antenna with DGS are compared with those of an array antenna without DGS in Figure 5.

As can be seen in Figure 5, at the resonant frequency, the reflection coefficient and the mutual coupling of the array antenna with optimized DGS are respectively about 2 and 3 dB better than the ones with the array antenna without DGS. As mentioned before, the side to side distance of array elements are about $\lambda_0/6$. Since the array elements are very close together, 3 dB improvement of mutual coupling is a good result.

To verify the presented method, the array antenna with DGS and conventional array antenna are constructed based on the result of design procedure and are shown in Figure 6.

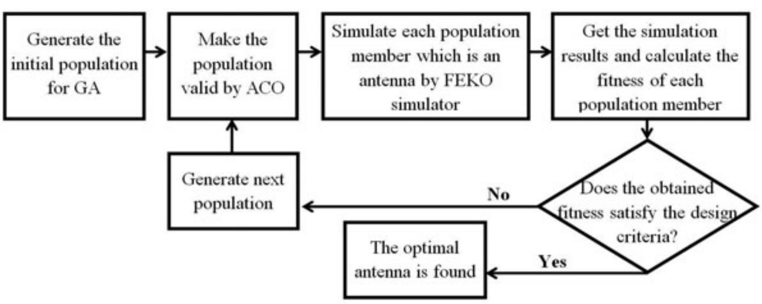

Figure 3. Flowchart of design method.

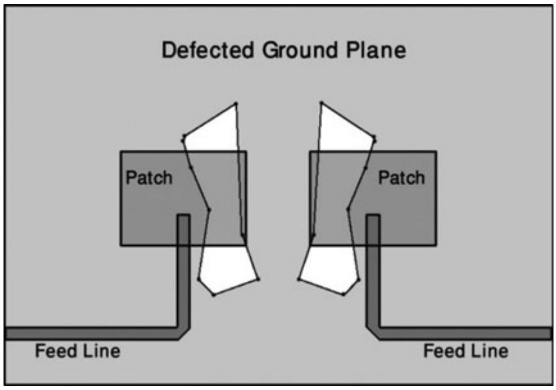

Figure 4. The optimal array antenna with DGS.

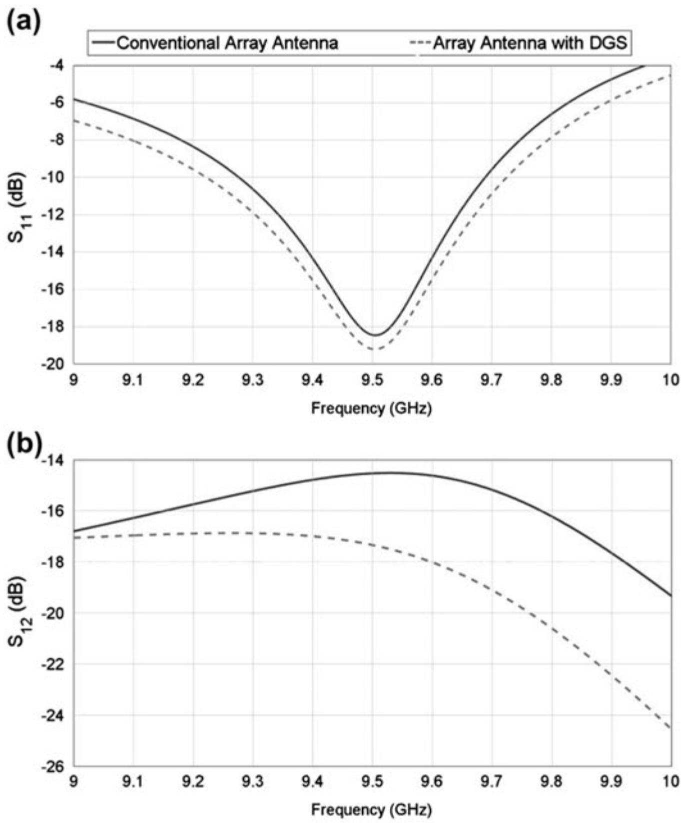

Figure 5. Simulated (a) Reflection coefficient and (b) mutual coupling coefficient of array antenna with DGS and conventional array antenna.

The measured reflection coefficient and mutual coupling of the array antenna with DGS and conventional array antenna are shown in Figure 7. As shown in this figure, the reflection coefficient of array antenna with DGS is improved about 6.5 dB and its

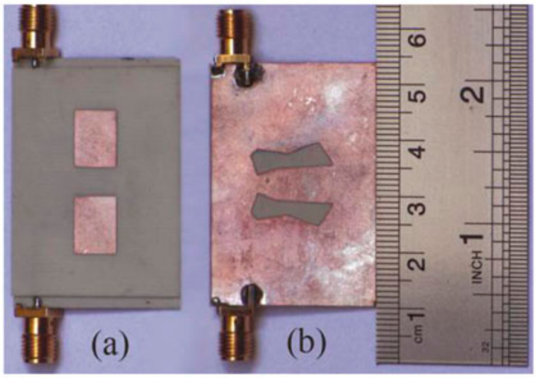

Figure 6. Fabricated array antenna, (a) top and (b) bottom view.

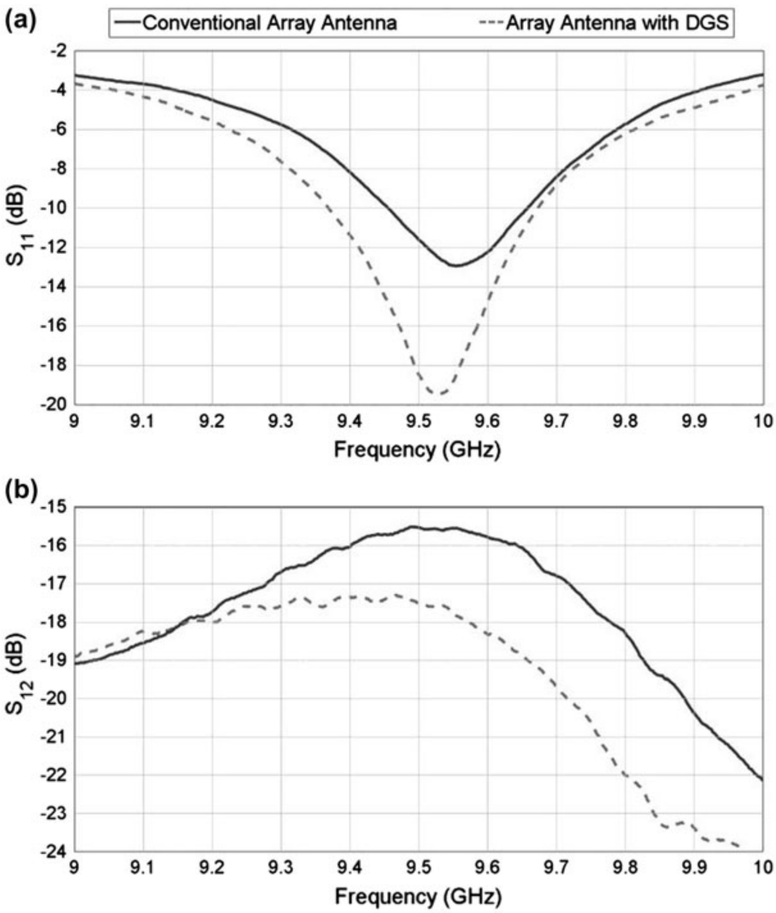

Figure 7. Measured (a) reflection coefficient and (b) mutual coupling coefficient of array antenna with DGS and conventional array antenna.

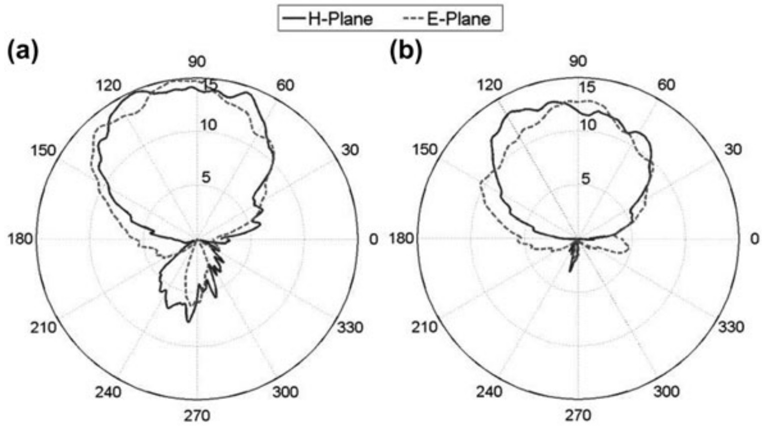

Figure 8. The gain radiation pattern of (a) proposed array antenna and (b) conventional array antenna obtained by measurement.

mutual coupling is about 2 dB better than the one of conventional array antenna. The measurement results have a great agreement with the simulation results; however, the resonant frequency is slightly shifted due to the fabrication process.

Figure 8 shows the radiation patterns of both array antennas at their resonant frequencies, 9.52 and 9.57 GHz for proposed and conventional array antennas respectively. The gain of array antenna with DGS is improved and is about 2.5 dB greater than the one of conventional array antenna. On the other hand, the back lobe level is increased in array antenna with DGS and its reason is the ground slots and it is the disadvantage of DGS.

The simulated and measured results show that the proposed method works as expected and by using this method an array antenna with the least amount of return loss and mutual coupling can be designed easily. In this paper, an array antenna with two elements is designed; however, the proposed method is flexible and can be used to design array antenna with more elements because a powerful optimization algorithm (GA) is implemented in this method.

Conclusion

In this paper, a new solution is proposed to decrease the mutual coupling effect in microstrip array antenna by using polygonal DGS. In this method, the slot shape of DGS is assumed to be a polygon, and the positions of polygon vertexes are determined by enhanced GA and ACO to obtain an array antenna with the least amount of mutual coupling and return loss. This method is verified by simulation and measurement. The return loss, mutual coupling, gain and bandwidth of the proposed array antenna are improved in comparison with the ordinary array antenna and the measurement results have good agreement with simulation results.

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