Reduction of Mutual coupling in Microstrip Array Antenna using Polygonal Defected Ground Structure

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***Abstract* —** The surface wave propagation is a significant problem in microstrip array antennas. Several methods have been reported to suppress the propagation of surface wave such as defected ground structure (DGS). The main problem in DGS is to determine the shape of ground slot. In this paper, a new method is proposed in which the slot is assumed to be a polygon and its shape is obtained by enhanced genetic algorithm (GA) and ant colony optimization (ACO) to have an array antenna with good gain and the least amount of return loss and mutual coupling.

***Index Terms* —** ACO, GA, microstrip array antenna, mutual coupling, polygonal patch.

I. INTRODUCTION

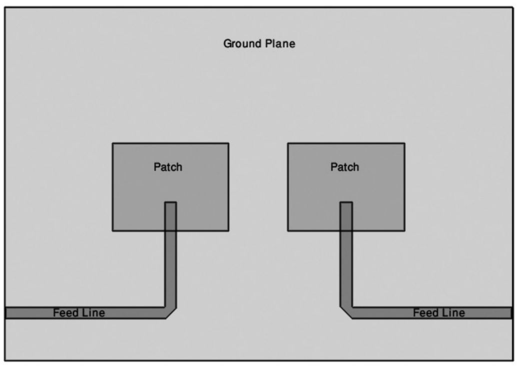
Microstrip antennas are used widely due to their advantages such as small size, low cost, light weight, and simple manufacturing. The microstrip antennas, also, have some disadvantages such as narrow bandwidth, low radiation power, and surface wave excitation [1, 2]. When microstrip antennas are used to form an array antenna, the excitation of surface wave is significant, and it causes mutual coupling in and array antenna. Several methods are presented to reduce the mutual coupling effect [3-7] and some of them focus on surface waves suppression [6-8].

One solution to reduce the excitation of surface wave is defected ground structure [9, 10]. The DGS is implemented by cutting a portion of ground plane; therefore, the current distribution of ground plane is disturbed. So, by controlling the shape of DGS, the excitation and propagation of electromagnetic waves in the substrate layer can be controlled. As a result, surface wave and mutual coupling can be reduced by choosing an appropriate DGS shape.

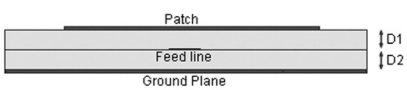
Some simple shapes for DGS have been studied in the literatures and an optimal shape is obtained by changing the size and position of these simple shapes [11, 12]. In this paper, a new method is proposed in which the shape, size, and position of ground slot is obtained by enhanced GA and enhanced ACO [13].

II. ARRAY ANTENNA STRUCTURE

An array antenna with two microstrip rectangular patch antennas is used in the simulation. The layer structure includes two substrates and three conductive layers which are finite ground plane, feed line layer, and patch layer. The thicknesses of substrates are the same and equal to $0.508\,mm$. The permittivity of dielectric layer is 3.38. The array antenna is designed at resonant frequency of $10\,GHz$ so its patches dimensions are $10\,mm$ and $7.5\,mm$. The patches are fed by proximity coupling method and the center to center distance between them are $15\,mm$. The dimensions of ground plane are $40 \times 43.5\,mm^2$. Array antenna structure and its layers structure are shown in Fig. 1-(a) and Fig. 1-(b), respectively.



(a)



(b)

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

III. DESIGN PROCEDURE

The DGS slot shape is considered as a non regular polygon. The number of polygon vertexes must be selected depending on the application needs. In this paper, slot shape is assumed to have 9 vertexes. Some constrains could be applied to the ground plane to simplify the design procedure. In this paper, the ground plane is assumed to be symmetric. But in array antenna with more elements, other constrains should be supposed.

The design procedure goal is to find the slot shape to have an array antenna with suitable gain and the least amount of return loss and mutual coupling. The mutual coupling in E-plane, H-plane, or both of them can be considered in the design method. But in this paper only the H-plane mutual coupling is considered in optimization procedure due to array antenna structure.

The slot shape is determined by positions of its vertexes, so the x and y values of vertexes are variables which must be optimized by enhanced GA. The x and y values of vertexes vary without any constrains in enhanced GA. So if they are connected together with a constant order, an invalid slot, that its edges intersect each other will be made as illustrated in Fig. 2.

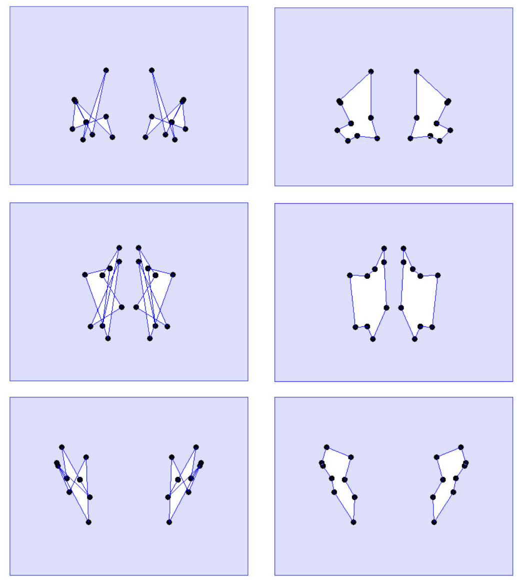


Fig. 2. Typical invalid ground planes (left column) and validated ones (right column).

To solve this problem, the correct order of vertexes connection must be found which can be achieved by enhanced ACO.

To do this, some artificial ants are generated and randomly placed on vertexes. Ants move from one vertex to another randomly and deposit trails of pheromone on their path. The ants' goal is to find the shortest path between all vertexes without intersection. In many cases, the shortest path is the path without intersection, so finding the shortest path is a good help to find the path without intersection. The ants move between vertexes with these simple rules [14]:

- 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 which have intersection with traveled paths.
- Ant prefers to travel through the path with more pheromone.

Some invalid ground planes and validated ones by ACO are illustrated in Fig. 2 and the flowchart of the mentioned method is shown in Fig. 3.

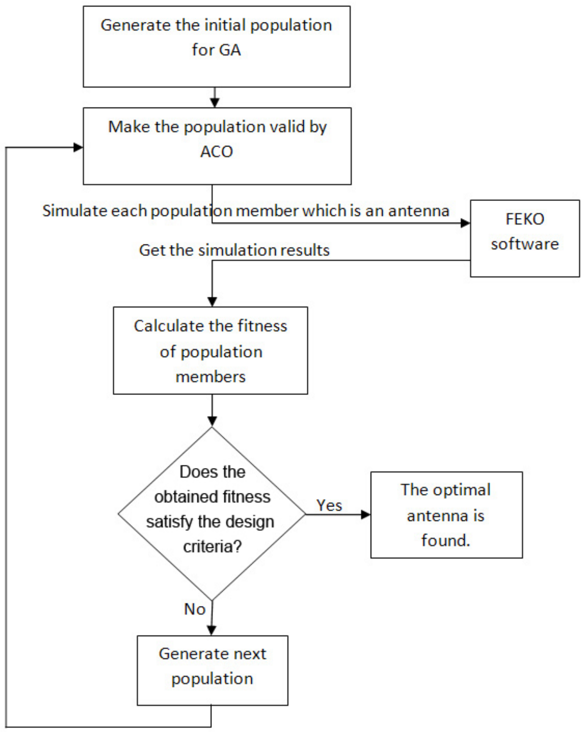


Fig. 3. Flowchart of design method.

The calculations of GA and ACO is run on the MATLAB [15] and the fitness of GA members, which are array antenna, is calculated by simulation that is based on the method of moments (MOM) [16]. Figure 4 shows an optimal array antenna which is obtained by the proposed design method.

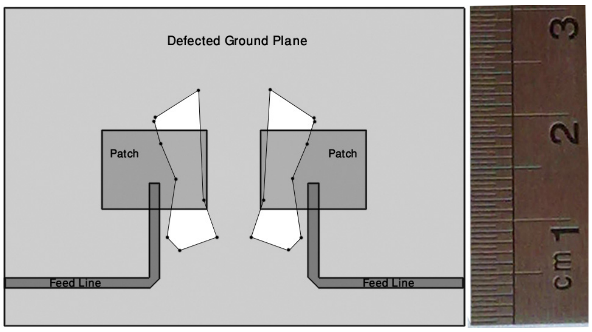


Fig. 4. The optimal array antenna with DGS.

The reflection coefficient and H-plane mutual coupling of array antenna with DGS are illustrated in Fig. 5 and are compared with those of the array antenna without DGS. As can be seen in Fig.5 the reflection and coupling of DGS array antenna are respectively about $3dB$ and $4dB$ better than the reflection and coupling of the conventional array antenna at the resonant frequency. Also, the VSWR bandwidth of the proposed array antenna is greater than the ones for the conventional array antenna.

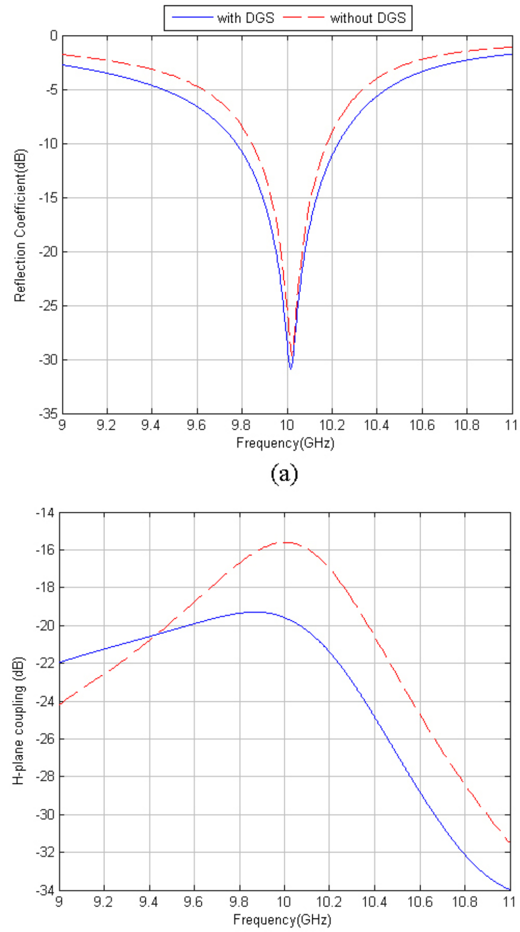


Fig. 5. Reflection coefficient (a) and the mutual coupling (b) of the array antenna with and without DGS.

The gain of the array antenna with and without DGS in $\theta = \varphi = 0°$ versus frequency is calculated and illustrated in Fig. 6. As shown in this figure, the gain and the gain bandwidth of the array antenna with DGS is improved. The dip in the gain graph shows that the radiation pattern of antenna is dependent on the frequency and the directivity of the array antenna at the resonant frequency is slightly decreased.

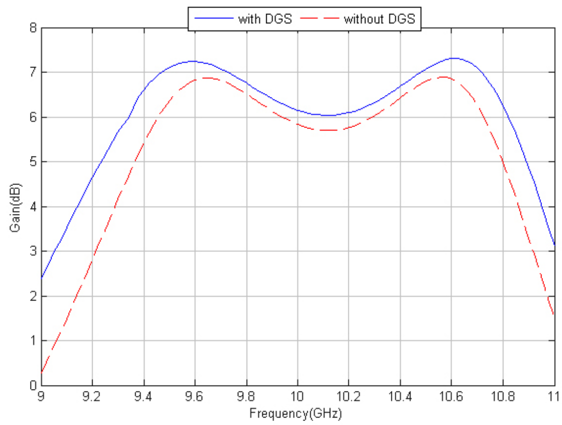


Fig. 6. Gain of array antenna with DGS and without it.

The radiation patterns of both array antennas at 10GHz are shown in Fig. 7. The back lobe level is increased in array antenna with DGS and it is due to the ground slots.

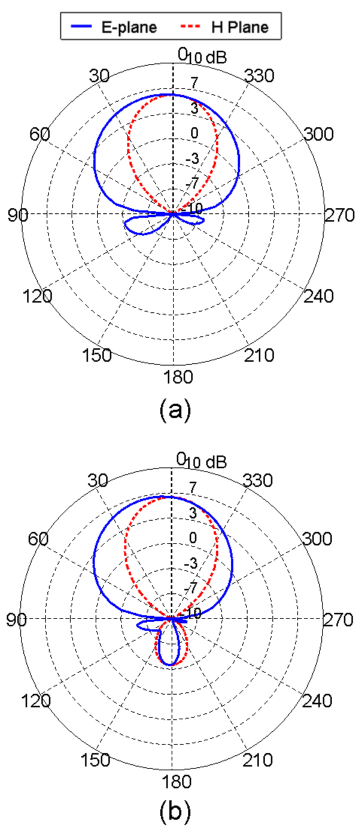


Fig. 7. Radiation pattern of array antenna without (a) and with DGS (b) at 10GHz.

The E-plane mutual coupling is not included in the optimization procedure. But it is simulated to show the effect of DGS on E-plane coupling. The array antenna structure to simulate E-plane coupling is illustrated in Fig. 8. The center to center distance between patches is 15mm. The E-plane couplings of an array antenna with and without DGS are plotted in Fig. 9.

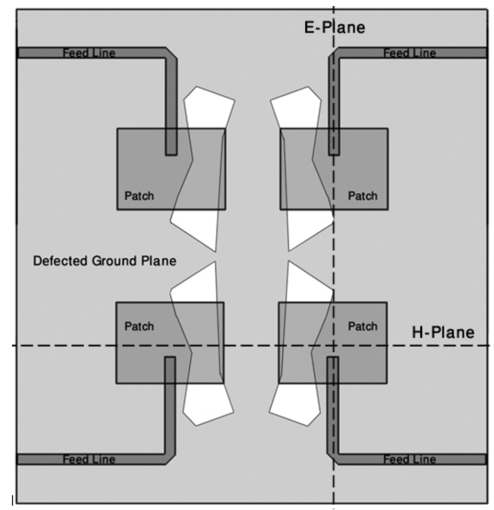


Fig. 8. Array antenna structure to obtain E-plane coupling.

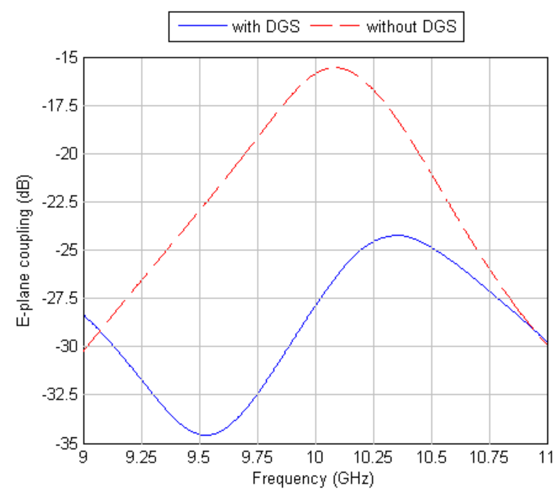


Fig. 9. E-plane mutual coupling of array antenna with and without DGS.

As shown in Fig. 9, the E-plane coupling of an array antenna with DGS is about 11dB better than coupling of array antenna without it and it shows that the DGS has a very good effect on the mutual coupling.

IV. CONCLUSION

In this paper, a new solution is proposed to control and decrease the surface wave of the array antenna. In this method, the shape of DGS is determined by enhanced GA and its results are verified by simulation. The return loss, mutual coupling, gain, and bandwidth of the proposed array antenna are improved in comparison to ordinary array antenna.

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