Cosecant Squared Pattern Synthesis for Reflector Antenna Using IWO

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Abstract—A method based upon Invasive Weed Optimization (IWO) Algorithms is described for the synthesize of double-curvature reflector surface to produce from a point source a shaped beam in one plane and pencil beam in the perpendicular plane. The method used the optimization algorithm to construct reflector surface by finding its central section curve. The synthesize procedure of this type antenna is discussed and the simulation results of a model antenna with a cosecant squared beam are shown and compared with Geometrical optics based method.

I. INTRODUCTION

Search radar antenna system often employs a shaped beam antenna which has a cosecant-squared pattern in the elevation plane and narrow pattern in the transverse plane. Doubly curved reflector antenna is a classical antenna for this purpose. The synthesis procedure based upon conservation of energy and the simple laws of geometrical optics (GO) has been described in details by many authors [1-6]. This method creates a differential equation or an integral equation that need to be solved numerically. Solving these equations need different parameters such as the parameter related to size of reflector that is arbitrary or an initial guess necessary for solving equation that has to be found. These requirements make antenna synthesize complicated and inflexible to achieve extra features like low sidelobe level or low ripple in shaped region. Recently, there has been a considerable attention paid to optimization algorithms in solving antenna problems. Therefore, to reduce the complexity and inflexibility of previously used methods, the authors employ the ability of optimization algorithm to create a new synthesize method. This method uses IWO as an efficient, simple and fast optimization algorithm method which was first extracted by [7], and successfully has been used in antenna design problems [8,9].

In this paper basic concept of GO synthesis is reviewed briefly and then a classical doubly curved reflector with a cosecant squared pattern will be designed and simulated.

Simulated results show that the new method has better accomplishments in cosecant squared region.

II. GEOMETRICAL OPTICS SYNTHESIZE

In order to shape reflector antenna’s surface to have a prescribed elevation pattern the proper central vertical section must be found. Central curve is illustrated in Fig. 1. Consider that the phase center of feed is located at origin \(O\). \(\varphi\) is the angle of incident ray with respect to \(z\) and \(\theta\) is the angle of reflected ray. The angle between incident and reflected rays, \(\sigma\), can be determined as follows:

\[
\sigma = \theta + \varphi
\]  

\(\rho\) is the distance from origin to central curve. Clearly \(\theta\) and \(\rho\) are functions of \(\varphi\) (i.e. \(\sigma(\varphi)\) and \(\rho(\varphi)\)). The differential equation of the central curve is [1-3]

\[
\frac{d\rho}{d\varphi} = \tan\left(\frac{\sigma}{2}\right)
\]  

In this equation, \(\sigma(\varphi)\) and \(\rho(\varphi)\) are both unknown. If know \(\sigma(\varphi)\), then \(\rho(\varphi)\) can be determined. This equation couldn’t be
Fig. 2 Radiation patterns of produced reflectors. (a) Initial produced reflector, (b) produced reflector in 15th iteration, (c) final optimum reflector surface solved analytically and has to be solved numerically.

The whole body of reflector can be constructed by locating parabolas in other plane, considering their proper directions [4]. They are responsible for producing narrow beam in perpendicular plane.

III. SHAPED REFLECTOR SYNTHESIS USING IWO

In this paper we employ the ability of IWO for synthesizing a doubly curved reflector antenna. Both antenna synthesis and its optimization are considered here and IWO will choose the best design depend on its defined goal. The synthesis method has the ability to define desired pattern and reach to it while in synthesis by GO method there is not enough flexibility in defining desired sidelobe level or limited ripple in the shaped region. The optimization algorithm tries to find the best reflector body which its characteristics is fitted on the desired characteristics. In synthesis procedure based on IWO, the main idea is finding a central section curve which can create a reflector body with desired shaped elevation pattern.

A. Invasive weed optimization (IWO) algorithm

IWO is an effective and robust optimization algorithm to find global minima as it has been shown in [7]. According to [7], the algorithm process can be summarized as follows:
1. A finite number of seeds spread out randomly on the search area.
2. They grow to flowering weeds and produce seeds. The number of reproduced seeds of each weed depends on its own fitness and better fitness permits more seeds to be reproduced. However, the maximum number of seeds is limited.
3. These reproduced seeds disperse over the search area around their parent weeds. The random dispersion has a normal distribution with mean equal to zero but varying variance (spatial dispersal). The standard the standard deviation (SD) decreases in each time step of algorithm and have a relationship with number of each step [7].
4. There is a maximum for number of weeds in each time step and only plants with better fitness can survive and produce seeds in the next step (competitive exclusion). The process continues until maximum number of iterations is reached and finally the plant with the best fitness is closest to the optimal solution.

B. Central curve synthesis using IWO

In order to determine central curve by means of optimization algorithm, at first, the curve must be expressed by a finite number of parameters. For example, curve’s function can be approximated to an n-th order polynomial. In this paper central curve is expressed indirectly. As it was described, if the distribution of $\sigma(\varphi)$ between $\varphi_1$ and $\varphi_2$ is determined, $\theta(\varphi)$ and $\rho(\varphi)$ will be determined respectively according to equations (1) and (2), and then the central vertical curve will be created. For approximating $\sigma(\varphi)$ distribution, various functions were examined to find a function with less parameter and well accuracy. The best choice was 4-th order polynomial. The polynomial coefficients are the optimization parameters.

$$\sigma(\varphi) = p_1\varphi^4 + p_2\varphi^3 + p_3\varphi^2 + p_4\varphi + p_5$$

IWO process starts with initial random coefficient of the chosen function for $\sigma(\varphi)$. Random surfaces will be generated until the optimum result is accomplished. The obtained elevation pattern by means of physical optics method is compared with the ideal sector cosecant squared pattern.

<table>
<thead>
<tr>
<th>$p_1$</th>
<th>$p_2$</th>
<th>$p_3$</th>
<th>$p_4$</th>
<th>$p_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.149</td>
<td>0.282</td>
<td>0.942</td>
<td>-0.304</td>
<td>0.16</td>
</tr>
</tbody>
</table>
Consequently, error (or fitness) value of weed (produced surface) is the difference between far field vertical plane pattern and a desired sector cosecant squared pattern. Optimization process continues until accomplishing a radiation pattern which is closest to our defined optimal goal.

IV. SIMULATION RESULTS

In order to show the ability of IWO algorithm in synthesizing this type of antenna simulation result is presented.

The reflector dimension is chosen arbitrary according to 10-db beam width of the feed in each plane. Moreover, it is fixed during all iterations. Optimization algorithm has been started and after 30 iteration the optimum solution or lowest fitness is achieved. The final values of $p_i, i = 1, 2, ..., 5$ are in Table I.

In Fig. 2 the far field patterns of produced surfaces during IWO iterations, are shown. It can be seen that they try to fit to their proper defined goal as the number of iteration increases. The dashed line in Fig. 2 represents the desired defined goal for elevation pattern in order to calculate fitness function. The final optimum reflector surface is presented in Fig. 3.

In order to comprise simulated pattern of the proposed method and the GO based method, another reflector in the equal conditions, same as feed position and reflector dimension is designed based on GO method. Fig. 4 compares the simulated results of the designed reflectors, one based on proposed method and the other employing classical method based on GO.

V. CONCLUSION

Invasive optimization algorithm (IWO), a novel stochastic algorithm has been successfully employed to create a flexible method to design doubly curved reflector antennas.

Totally synthesis procedures based on optimization algorithms can reduce the complexity of problem and improve the flexibility in design goals and antenna performance. To improve antenna performance other antenna parameters such as positions, orientations and feed excitation can be set as other optimization parameters. Furthermore different types of desired goals can be defined to be optimized. The validity of the proposed technique is verified by designing the fixed antenna set, using the described methods.

REFERENCES