SYNTHESIS OF APERIODIC ANTENNA ARRAY FOR ISOFLUX RADIATION IN SATELLITE APPLICATIONS BASED ON GENETIC ALGORITHMS

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Introduction: Nowadays, a variety of applications involving the well-known antenna arrays for wireless communication systems exists because of their great capabilities of radiation. The considerations for their radiation synthesis are commonly for reducing certain issues presented in the systems. Essential issues could be found in the case of satellite applications. For instance, the electromagnetic fields transmitted from the on-board antenna to the earth are attenuated in the coverage area far from the nadir direction and/or near the horizon. This is due to the path loss variation as well as the atmospheric conditions [1]. This is an unwanted satellite communication factor in the transmission for radio, television or global positioning services. Usually, large antennas as reflectors are utilized for this purpose [2]. Nevertheless, the communications are not propitious as well because of the transmitted power to overcome the attenuation is too high for the complete antenna system. These circumstances may be mitigated by the antenna system with an isoflux radiation.

The state of the art research for isoflux radiation antenna includes the design for antenna arrays with uniform spacing [3]. However, these results complicate the feeding network implying higher cost of hardware due to the great number of excitations. As a rule, the hardware in the satellite has to be reduced as the best as possible. For instance, a design for an aperiodic antenna array considering a deterministic approach to optimize the inter-element spacing with no side lobe level reduction for LEO satellites is presented in [4] and for GEO and MEO in [5]. At this point, the synthesis for aperiodic antenna arrays is increasingly suitable for the satellite applications. In this case, an important issue is to reduce the excitations as the best as possible in an aperiodic array. The most significant aspect that is unique to this research is the synthesis of aperiodic antennas for satellite applications optimizing positions and reducing excitations distributions to achieve the desirable shape pattern. Depending on the performance requirements, the presented design could lead the satellite hardware to be reduced significantly due to the use of less excitation devices. This synthesis is carried out by using the well-know method of Genetic Algorithms (GA).

Aperiodic array model: Consider an aperiodic array of \(N\) elements in the \(X\) axis as shown in Figure 1. The array factor for the aperiodic array shown in figure 1 is given by the next expression:

\[
AF(\theta, \phi, S, W) = \sum_{n=1}^{N} w_n e^{j k (x_n \sin \theta \cos \phi + y_n \sin \theta \sin \phi)}
\]

Fig. 1: Aperiodic array antenna

where \(k=2\pi/\lambda\) is the phase constant; \(\theta\) is the angle of a plane wave in the elevation plane; \(\phi\) is the angle of a plane wave in the azimuth plane; \((x_n, y_n)\) represents the positions of the element \(n\) on the plane \(XY\) defined by the set \(S\); \(w_n\) represent the amplitude excitations of the element \(n\) defined by the set \(W\). The array model is replicated to the negative part to obtain symmetry with respect to the \(X\) axis.
Problem statement: In the satellite applications, it is required uniform earth coverage. In this case, an isoflux pattern is a radiation with no variation in the strength power density to any point of the illuminated earth surface. Since this framework, an accurate radiation pattern can be calculated as a function of $R_s$ in the coverage area as follows:

$$R_s^2(\theta) \left( \frac{\sin^2 \theta}{b^2} + \frac{\cos^2 \theta}{a^2} \right) + R_s \left( \frac{-2(h+a)\cos \theta}{a^2} \right) + \left( \frac{(h+a)^2}{a^2} - 1 \right) = 0$$

Where $R_s$ indicates the relative distance of the satellite to any point of the illuminated earth surface; $h$ represents the height of the satellite and $R_s$ is the distance of the earth center to any point of the illuminated earth surface; $a$ is the equatorial radius of the earth; $b$ is the polar radius of the earth. The fitness function of this design problem is formulated as follows:

$$o_f = \left| AF(\theta_r, \phi, W, S, P) - R_s^2(\theta) \right|^2 + \left| AF(\theta_{SLL}, \phi_{SLL}, W, S, P) / \max \left( AF(\theta, \phi, W, S, P) \right) \right|$$

where $\theta_r$ is the range of the elevation plane for the coverage area; $(\theta_{SLL}, \phi_{SLL})$ is the angle where the maximum side lobe level is attained; in this design problem, a genetic algorithm is applied to find out the distributions of the array to achieve the desirable shape pattern.

Simulation Results: It is proposed an aperiodic array with $N=32$ elements distributed in the plane $XY$ axis. The population size was set to $N_p=200$. Adaptive crossover and mutation operators are used. The stopping criterion is 1500 iterations. In this document, it is presented an example for a satellite with an altitude of 20000 km. In this case, the prescribed pattern is established with an angle of elevation of $\theta_e=14^\circ$ enough to illuminate the earth with an attenuation of -2.1 dB in the nadir direction. For these antenna array designs, the aperture is established to be in the range of $-2\lambda \leq x_\theta \leq 2\lambda$ and $-2\lambda \leq y_\theta \leq 2\lambda$. Also, the array design considers just two levels of amplitudes and no-phase excitations.

As shown in figure 2, the optimization provides the normalized array factor for an isoflux radiation with $SLL \leq -10$ dB. For this design, under the assumption of the requirement of reducing the excitation devices in the antenna system for satellites, the optimization obtained an acceptable side lobe level reduction and the isoflux radiation with the required power suppression in the nadir direction.

Conclusions: This research reported an aperiodic array for satellite applications with an isoflux radiation by using genetic algorithms. The aperiodic array could provide the isoflux radiation with a considerable reduction of the hardware in the antenna system for satellite applications. This aperiodic array design could simplify the feeding network for an isoflux radiation.

REFERENCES


