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INTELLIGENT DESIGN OF THINNED PHASED ARRAY- AN APPROACH

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Abstract- A modern multi-mode phased array radar is a complex system capable of performing multiple functions of search, acquire and track multiple objects simultaneously. It generally consists of thousands of Transmit/ Receive antenna modules. This paper discusses certain basic issues of applying AI technique for reducing the total number of active antenna modules in the phased array.
Keywords- Phased array radar, Artificial intelligence, Genetic algorithm

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Introduction

Radar is an electronic device for the detection and location of objects primarily employed by armed forces of a country to avoid enemy's intrusion into their territory. It operates by transmitting an electromagnetic wave and detects the nature of its echo from the object being detected. Capability of modern multi-mode phased array radar mostly comes from its active aperture antenna system, consisting of radiating elements, Transmit / Receive modules, beam steering unit, thermal management unit, Built-in test unit etc. Sensitive nature of such large number of RF components together with the array lattice and element density aspects governed by the system requirements pose a challenge for phased array design engineers. The major problem comes from thermal management, power dissipation and reliability of the antenna subsystem in these radars. A method of reducing element count, cost, Ease of Use, weight, power consumption and heat dissipation is to 'thin' the array, by removing a certain percentage of array elements, according to a suitable strategy.

This paper suggests a method of using Genetic algorithm for reducing the active element dynamically based on real time requirements.

The paper is organized in the following way. In Section II we give the background of the problem and its complexities. Section III is about the concepts which can be used for solving the problem. Section IV discusses some simulation results and Section V gives the conclusions.

Background Information

Figure.1 shows the multi-function capability of phased array radar. The basic block schematic of a modern active aperture phased array radar system is given in Figure. 2[1].

Design complexity issues

Typically radar of this type can consist of a few thousands of active T/R modules. A typical T/R (T/R standing for transmit/ Receive) module would consist of Low noise amplifier, digital phase shifter, a digital attenuator and some T/R switches. In addition it will have some circuitry for driving the module from a centralized computer, some RF protection device and the radiating element. It may also have some other circuits depending on the specific nature of the system. Many of these components would be based on Microwave Integrated Circuit (MIC) and Milli-metric wave Integrated Circuit (MMIC) technique. A typical array antenna head showing thousand of these modules is shown in Figure. 3.

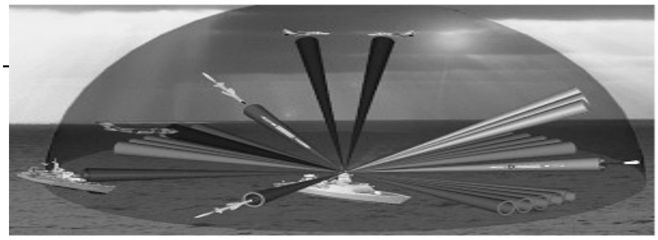

Fig.1- Multi mission capability of phased array radar

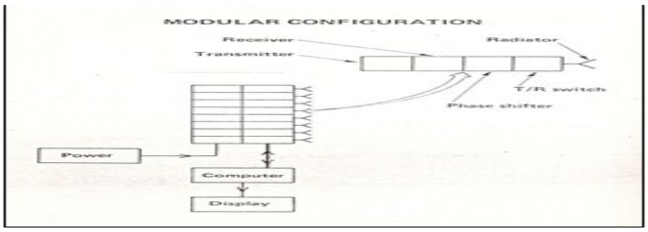

Fig.2- An active aperture Phased Array Radar

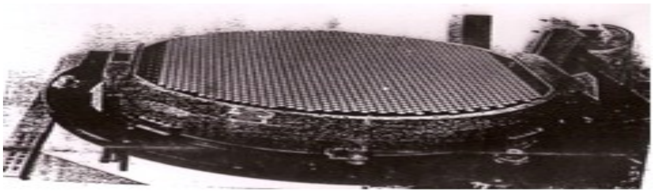

Fig.3- A phased array antenna head

There are three major issues which dictate the design of the phased array antenna head as described above.

- Very large number of modules placed in a tightly packed array lattice based on antenna considerations such as grating lobes, mutual coupling etc
- The antenna head is the interface between the radar and external environment, and hence cannot be covered in any enclosure; thus is subjected to harsh environment in spite of some protection from a possible radome.
- Many of the MIC and MMIC circuits inside the modules are extremely sensitive to thermal conditions which are difficult to alleviate.

Thus, thermal management, power dissipation and reliability of the antenna subsystem in these radars pose a major challenge. A method of reducing element count, power consumption, heat dissipation and consequent reduction in cost and weight, is to 'thin' the array, by deactivating certain percentage of array elements, according to a suitable strategy.

Applicability of thinning concept to phased array

Concept of thinning an antenna array is not new. Empirical [2], Numerical [3] and stochastic techniques [4,5] have been suggested in the past for design of thinned antenna arrays. These approaches provide useful guidelines for design of a thinned array for specific radiation requirements, such as say to obtain a side lobe level better than a specified value for a required scan angle, However, the phased array concept is based on adaptation to changing requirements, including steering of beams as per demand on real-time basis. Thus designs based on those approaches are not be directly applicable.

The proposed methodology suggests some simple modifications by which Simple Genetic Algorithm (SGA) can be adapted for changing or dynamic conditions, including scanning beams

Adapting SGA for Phase Array Design

Simple Genetic Algorithm (SGA) [6] can be successful in synthesizing a thinned array by considering it as a combinatorial optimization problem. The goal is to strategically remove a subset of active elements in the array subject to some constraint. This problem is binary in nature when active elements are represented by a value of '1' and inactive elements are represented by a value of '0'. The problem then becomes how to choose a specific combination of 1's {Nactive} and 0's {Ninactive} to meet the requirements under the constraints.

Even though SGA is a well suited tool for solving array thinning problems, three factors figure prominently in applying the algorithm effectively for dynamic thinning

Solution Space Problem

A practical phased array antenna consists of thousands of elements. In such cases the solution space would be very large and also rugged. Exploring such a large solution space using SGA would not only require time but also may result in getting trapped in a local minimum leading to premature convergence.

The problem can be understood by considering a simple example of an array consisting of just 100 elements. Assuming the array to become 20% sparse, there will be about 20 elements which have to be made 'off'. The design question is to find out a set of not more than 20 elements that can be switched off without seriously affecting the performance of the radar. For this to be established, a total possible 2.4×10^8 solutions have to be examined before taking a decision. Extrapolate this to an array of say 4000 elements, and one can estimate the sparse array design intricacy!

Table 1- gives an estimate of solution space for different conditions

Table 1. Size of Solution space for different conditions

Total Number of elements	Number of 'On' elements	Size of Solution space
32	24	7
64	48	127
128	96	32767
256	192	2.1475×10^9
256	128	9.2234×10^{18}

Objective function evaluation

For large arrays, requirements of computer resources for Objective Function (OF) evaluation far exceed the functional requirements for implementation of SGA.

OF is based on calculating the array factor AF (θ, φ) is given by

$$AF(\theta,\varphi) = 4 \sum\sum Inm \cdot \cos[\Pi \cdot (2n-1) \cdot \sin(\theta)\cos(\varphi)] \cdot \cos[\Pi \cdot (2m-1) \cdot \sin(\theta)\sin(\varphi)] \quad (1)$$

Evaluation of OF is required for every population in every iteration. Such computationally intensive procedure becomes a major issue which needs to be resolved if SGA has to be adapted for phased array design on a real time basis.

Moreover for a real-time scenario where time is at premium, a solution which gives a near-optimum value would be a more useful

input than the absolute minimum value of N active , as far as the OF is satisfied. The penalty paid in terms of extra time spent for obtaining the exact minimum solution may defeat the very purpose of the mission in such cases. Also, for practically applying the result, knowing all the elements of the set {N active} is more important than merely knowing the minimum value of N active.
Thus, SGA should look for acceptable solution rather than the absolute minimum value of N active. However, what is an acceptable solution would depend on the operational scenario.
Methods suggested in the present study for mitigating above issues are through

- Zoning technique
- Bulk array computation and
- Dynamic Thinning Programmer.

The first two are related to reducing time of design computation and the last to system integration.

Zoning Techniqu

Zoning refers to partitioning of the antenna array into convenient zones, so that the solution space can be usefully explored. Zoning technique provides ample scope for using any a-priori or intuitive information about the antenna array. By this approach, considerable reduction in solution space occurs, resulting in fast convergence as demonstrated below
Figure-4 gives the results on convergence of thinning a linear array of 200 elements. The Redlines indicates the trend for 10 runs of SGA without zoning and blue lines show the trend after using zoning technique.
Clearly, convergence is faster, when zoning is used.

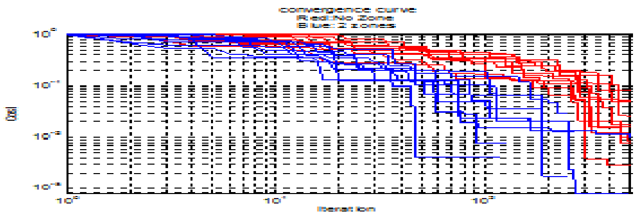

Fig.4- Convergence trends with and without zoning

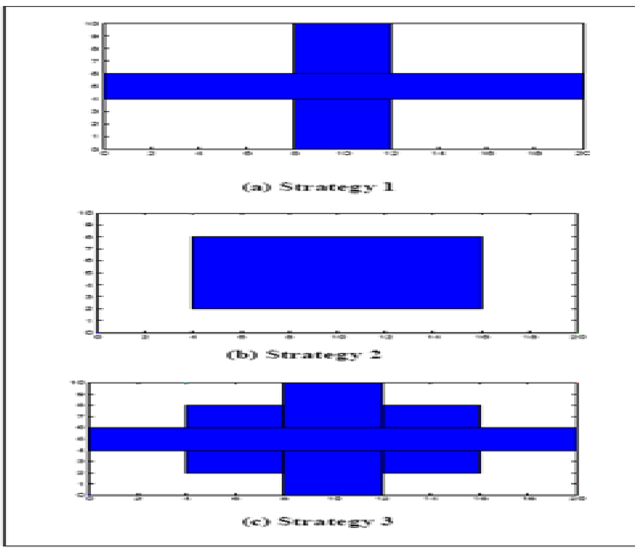

Fig.5- Some strategies for zoning a phased array antenna aperture

Same concept can be extended to planar array. Three possible strategies for zoning found useful in case of planar phased array are shown in Figure-5.

Bulk array Computation (BAC)

Implementation of GA requires evaluation of OF for every member of the population in each iteration for a large set of angles{θ,φ} . Each of the evaluation is based on the Array Factor (AF) calculation using equation (1), which is highly nonlinear and involves lengthy procedures. Thus, for large arrays, requirements of computer resources for objective function evaluation would far exceed the functional requirements for SGA.
'Bulk Array computation' (BAC) involves first storing the data of the radiated fields of all elements in all directions. The effect of 'inactive elements' is then coalesced on the stored data of the radiated field of the array. Based on this, radiation pattern of the thinned array corresponding to each member of the population is then computed
Major steps involved in the computation are

- Generate data for creating 'Element Table' which has all details about element location and its complex excitation coefficient.
- Generate data for creating 'Angle Table' which contains details of each angular direction in (θ, φ) coordinates
- Compute and store the radiated field due to each element of the array in each direction of interest
- Initial population of 'inactive elements' is generated.
- Effect of 'inactive elements' is then coalesced on the stored data of the radiated field of the array; radiation pattern of the thinned array corresponding to each member of the population over the required angular sector is then computed.
- Feedback parameter is extracted from the set of radiated patterns of the thinned arrays and is used in iterative manner to generate successive populations, using SGA procedures.
- This is continued iteratively till the terminating criteria is obtained

Initial estimate of reduction in time for OF evaluation is of the order of 85% by using BAC method. This will depend on many parameters including the total number of elements, thinning factor and others. But the reduction in computational operations range from about 2.8 X 108 in case of a simple 200 element linear array to about2.32X 10 12 in case of a planar array of 4096 elements.

Dynamic Thinning Programmer

Thinning concept explained above can be integrated into a phased array system, by having a Dynamic Thinning Programmer (DTP) unit. Conceptual working of DTP is shown in Figure 6.

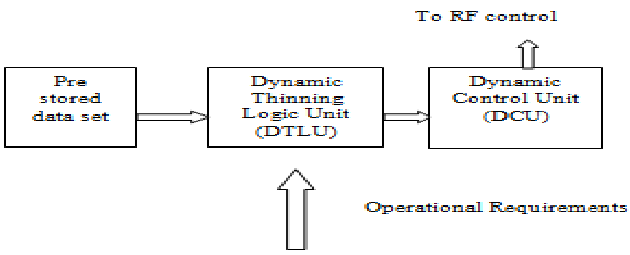

Fig.6- Configuration of a Dynamic Thinning Programmer

Based on the input information about the scan direction, Dynamic Thinning Logic Unit of the DTP can retrieve data about the on/off requirements of the array elements.
This data can be in the form of a look-up table inside the pre-stored data console within DTP. This data generates control signals which manipulate the on/off conditions of RF modules within the RF manifold

Typical Result

Techniques discussed above were used to simulate thinning of a 64 X 64 element planar array, scanned to different angles in the two planes. Typical Radiation pattern for a scan angle of 30 degrees in both the principal planes is as shown Figure-7.
Further studies were taken up for obtaining an 'acceptable solution' for a thinned 64 X 64 array with -40 dB side lobe level for all scan conditions. Figure-8 shows typical scan diagram for one of such results. The diagram gives the sidelobe level for nine different scan conditions. In all these cases, only 2784 elements out of N_{total}=4096 elements were active. It can be observed that the results are acceptable solutions. Thus zoning and BAC when used together has helped in achieving an acceptable solution even when the array size is as large as N_{total}=4096 elements.

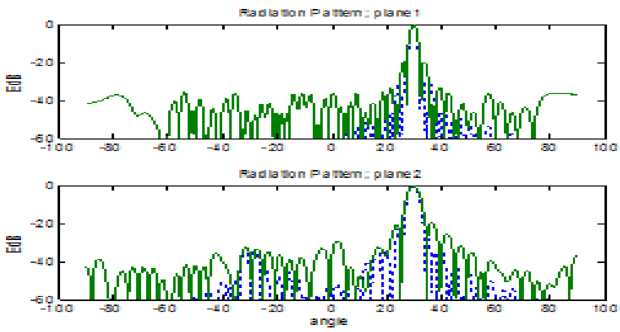

Fig.7- Radiation pattern for scanned to 300 in both the planes theta of Thinned 4096 element planar Array
((Blue ---Full Array; Green :Thinned Array

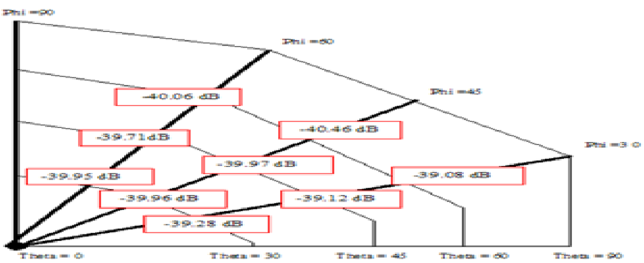

Fig.8- Scan diagram for a thinned 4096 element array

Conclusions

Simple Genetic algorithm can be used for reducing the active element dynamically in phased array radar based on real time requirements. However this will require adapting certain special techniques such as zoning and Bulk Array Computation as described in the study. Practical implementation shall be through a Dynamic Thinning Programmer which can act as interfacing unit between the phased array antenna and the main radar.

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