

Soft Computing in Antenna Arrays

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The applications of soft computing techniques for the design and maintenance of large antenna arrays is discussed. Of particular interest is the design of complex beam shaping arrays using Genetic Algorithms. Also, the possibility of using Neural Networks for various types of faults in large arrays meant for high speed target tracking radars is explained in detail.

As the size and complexity of the antenna array increases, the realization of the excitation values (both amplitude and phase) becomes tough. There are numerous techniques available in the literature where most of them are computer intensive and highly mathematical. Also the designer has to redo the entire mathematics even if the design changes slightly from one system to another. This puts tremendous load on the design wing of the company. In this direction, our group made some attempts to simplify using soft computing techniques. Genetic Algorithms is one such convenient technique. These algorithms are stochastic search methods that mimic the metaphor of natural biological evolution. Genetic algorithms operate on a population of potential solutions applying the principle of “survival of the fittest” to produce better and better approximations to a solution. Here, we start with many possible solutions simultaneously and go on reducing the error between the desired and obtained results. This may appear to be absurd in the initial stages but would definitely yield highly accurate solutions after a series of trials.

On the other hand there are many practical difficulties while ensuring that all the elements of the array are functioning properly to yield accurate radiation/receiving pattern. This ‘once in a week’ ritual is a big pain for many engineers because there is no guarantee that they will be able to find the fault and fix it within the acceptable down time. Hence, a neural network approach is suggested to run the fault finding mechanism simultaneously while the system is in its normal functioning mode delivering its vital data.

Genetic algorithm approach is adopted to synthesize arrays to produce desired beam shapes. This approach has the advantage that several design criteria required to comply with EMC standards can be met in one synthesis procedure simultaneously.

In the earliest work, as a proof of the principle, GA approach is adopted to obtain cosecant beam shape. 10-element broadside array with isotropic elements is considered. Each gene consists of 5 bits to represent the amplitude excitation of the individual element in the array. But only symmetrical patterns are obtained. So, another 5 bits are added to represent phase of the excitation and sign by one bit. With this rms error between the desired and observed pattern is approx. 15% after 500 generations. The pattern obtained is compared with the desired pattern in the fig1. The error reduction pattern with generations is demonstrated in fig. 2.

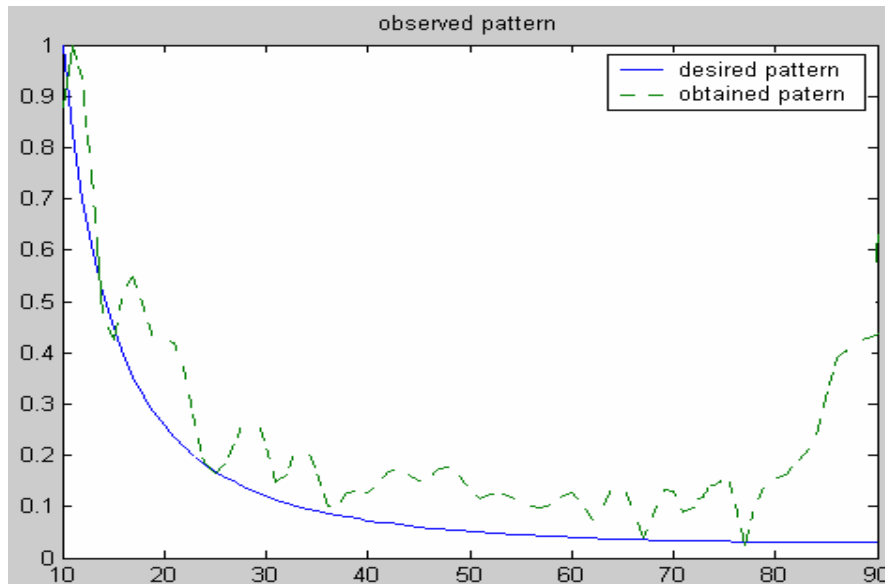


Fig.1. Comparison of desired and obtained patterns

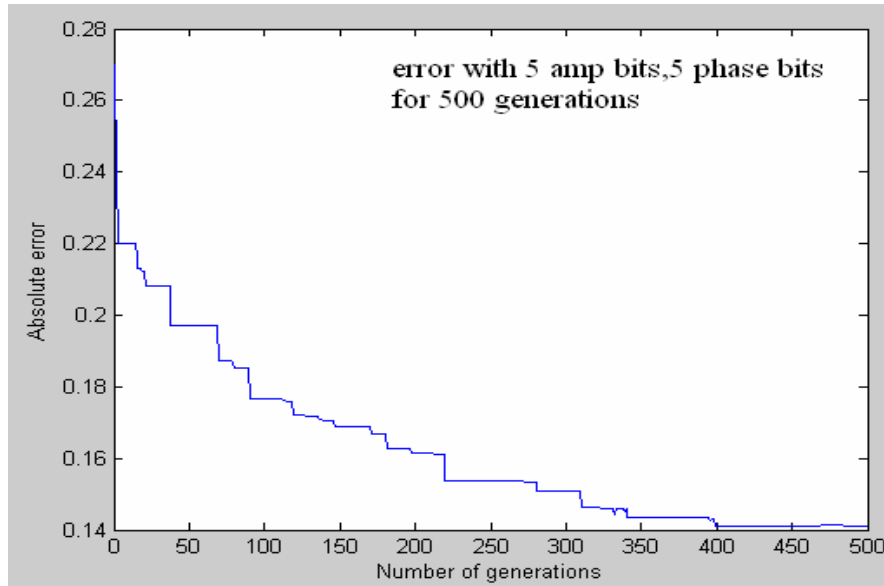


Fig. 2. Monotonic decrease of error with number of generations

So, in order to increase the accuracy, the no of bits have been increased to 15 where 7 bits are for amplitude, eighth bit is sign bit and the last 7 bits are for phase, though it may not be physically realizable. By this effort, the error could be made half as displayed in fig.3. Corresponding error decreasing pattern is presented in fig.4.

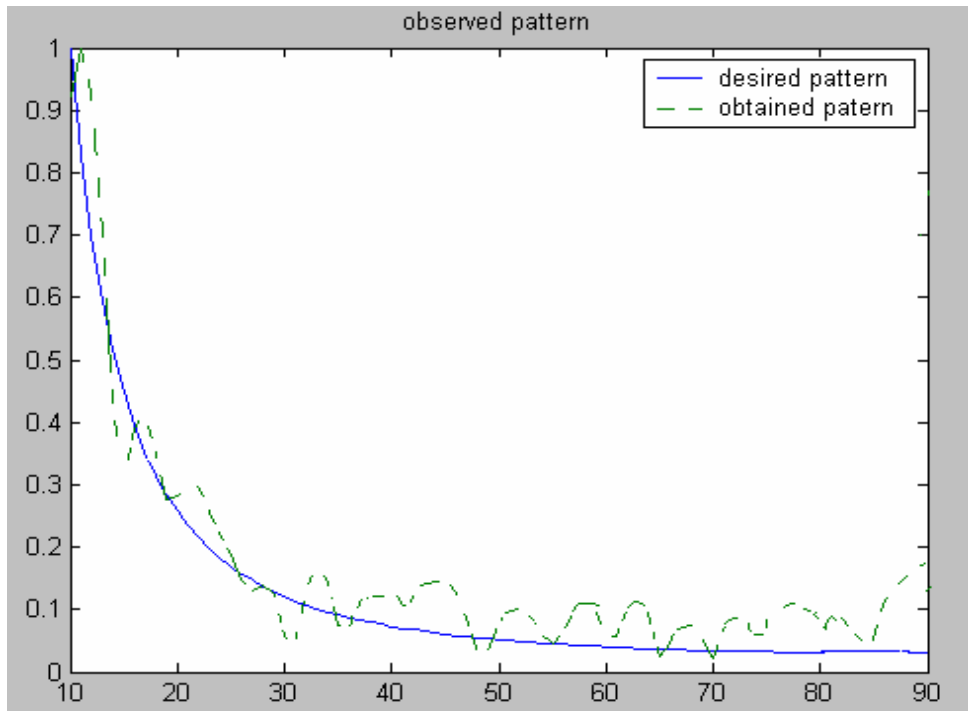


Fig. 3. Comparison of desired and obtained patterns with 15 bits of excitation

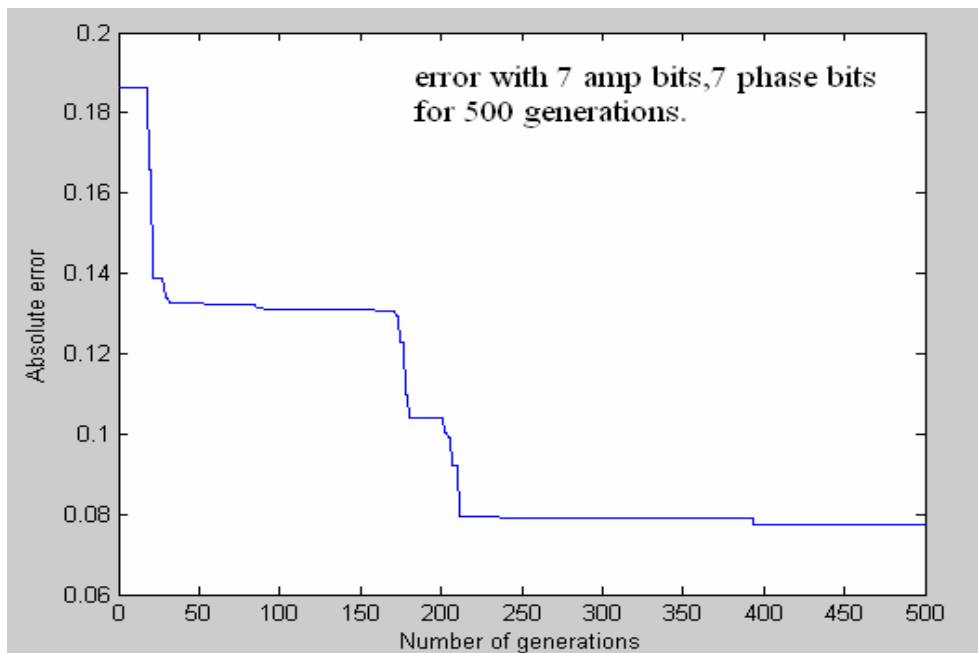


Fig. 4. Montonic decrease of error with generations (no. of bits – 15)

In second exercise, multilook beam synthesis is attempted for a base station antenna design of cellular network. Here, the upper half of the sorted excitation sets out of the total excitation sets and the first and second chromosomes are taken as first couple for crossover operation. Then third and fourth chromosome will be taken as second couple and so on. So, the children replace the second half of the gene pool. Better results are obtained by random picking from mating pool. To avoid chances of good gene in the bad chromosomes being discarded, the gene pool is ranked after crossover in initial generations and approximately 3% of the bits in every chromosome are mutated randomly. For a good match between desired and obtained patterns, it is found that six amplitude bits and six phase bits will be necessary. The number of generations needed is around 500 for the rms error between desired and obtained patterns to be within 5%. .

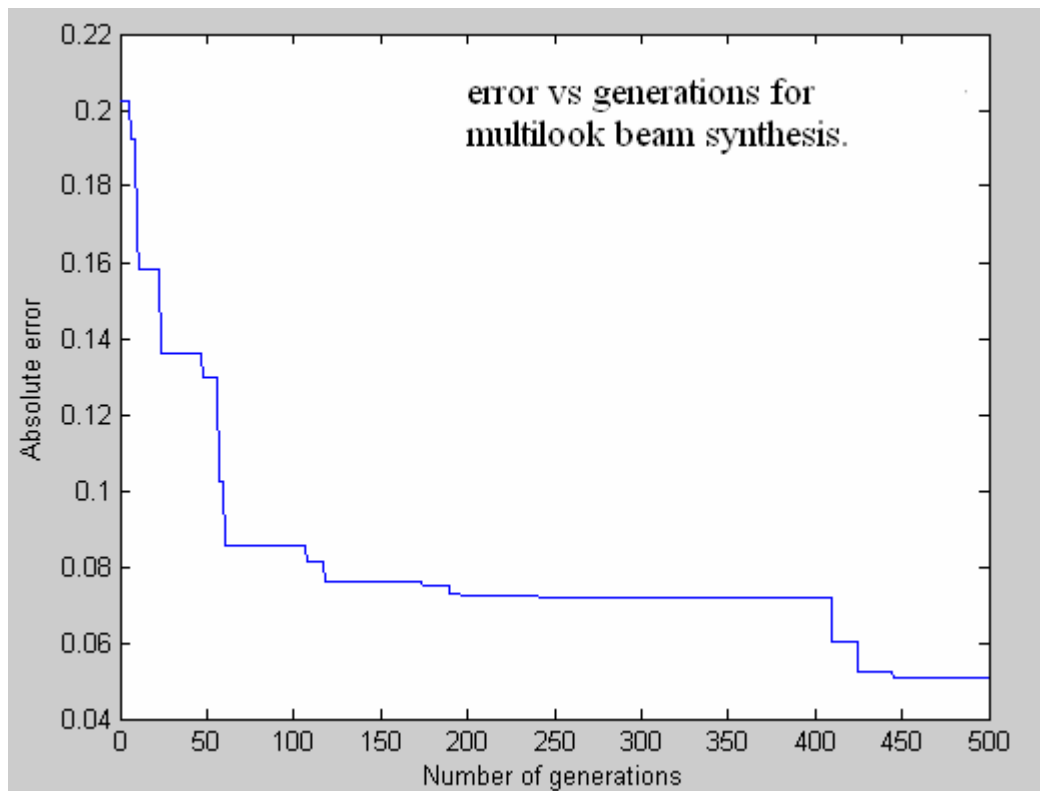


Fig.5. Monotonic decrease in error with generations (multilook beam)

In third exercise , a new method for the beam shaping of circular array antennas using genetic algorithms is proposed. To elucidate the advantage of this, an Elliott pattern with a flat top beam is synthesized.

Initially 170 bits are randomly generated for a 17 element array. Parents are selected by roulette-wheel selection process. Firstly, different crossover techniques such as single point, multipoint and uniform crossover are implemented. Among them single point crossover gives good result.

There are two aspects in this crossover operation on which most of the experimentation is performed. They are choosing of appropriate crossover point, and whether to perform the crossover operation over the entire chromosome or for each individual element in the entire chromosome.

So single point crossover is implemented for 170 bits at first. Even though the error is minimum, the overall pattern is not acceptable in the side lobe region. So later element wise crossover is done which gave the better result. A number is generated randomly between 1 and 10, such that corresponding elements are crossed over.

The selection of number of bits to be mutated was a tough decision to be made. This is because the error increased both ways when the numbers of mutated bits are more or less. We had to mutate 2 to 3% of the total number of bits in every chromosome of the gene pool. Compared to rms error, ranking the gene pool with absolute error is preferable to obtain better results.

Pattern obtained by considering the rms error:

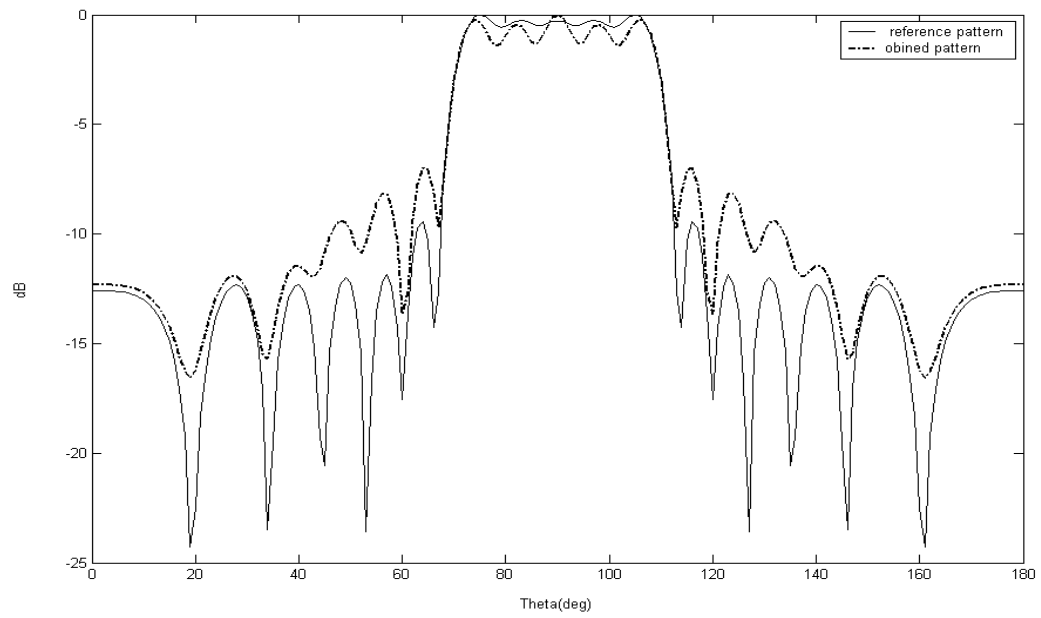


Fig. 6. Desired and Obtained patterns (Elliott's pattern)- rms error optimization

Pattern obtained by considering absolute error:-

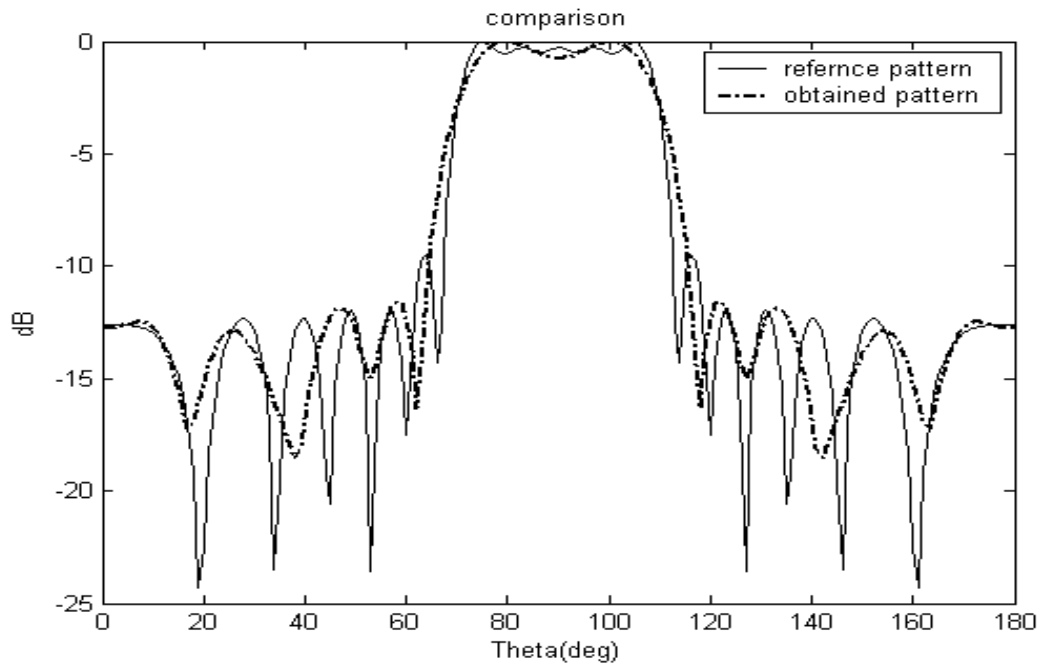


Fig. 7. Desired and Obtained patterns (Elliott's pattern)- absolute error optimization

In normal optimization the error for whole radiation pattern is minimized at once considering all the array elements at once. Compared to this, section wise optimization is more convenient to obtain the desired result with less number of generations.

In section wise optimization the elements in the array and the radiation pattern are divided into equal number of sections. After section wise minimization again the whole pattern is considered and error is minimized for best results.

optimization of main lobe :

In this ,the section corresponding to the main lobe,i.e, the section containing the elements 6 to 12 is optimized which gives a main lobe closer to the main lobe of the reference pattern

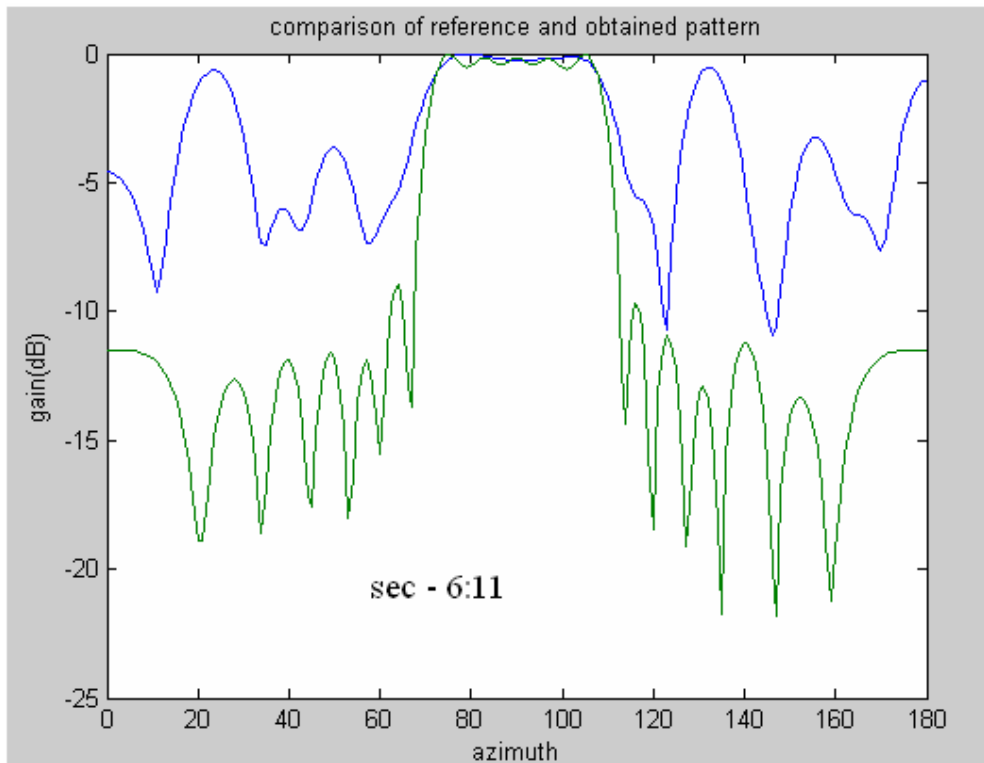


Fig. 8. Desired and Obtained patterns (Elliott's pattern)- Main lobe optimized

Optimization of side lobe:

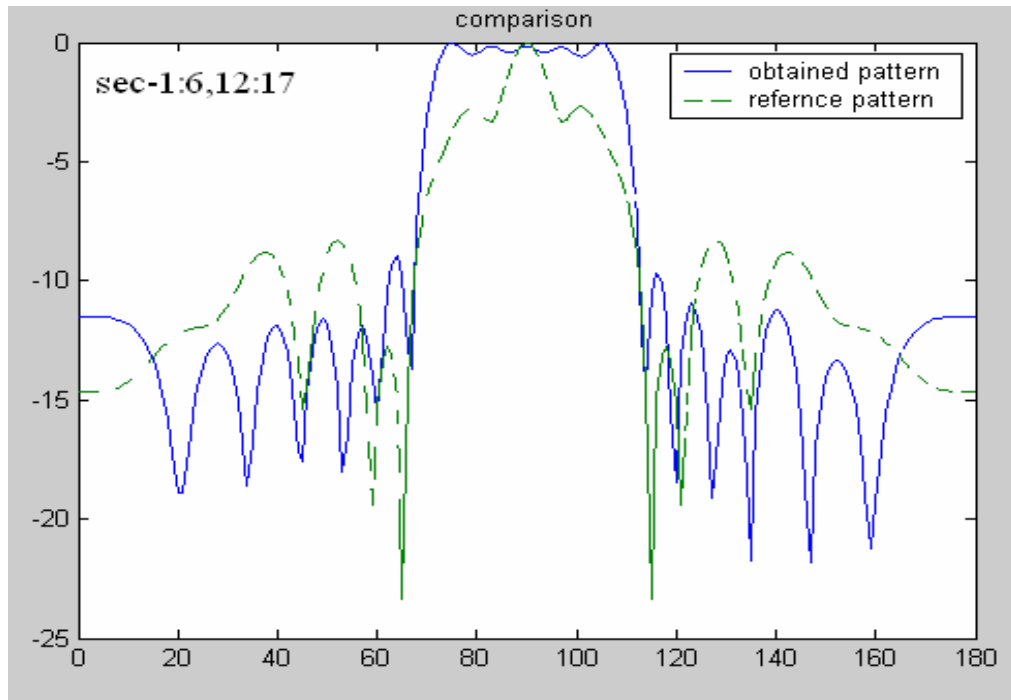


Fig. 9. Desired and Obtained patterns (Elliott's pattern)- side lobe optimized

The binary string of the chromosome is considered to be in Gray code to increase the randomness of the search space. With this, the required pattern is obtained after 500 generations with an absolute error of 0.026 in the main lobe and an average error of 0.012 in the side lobe.

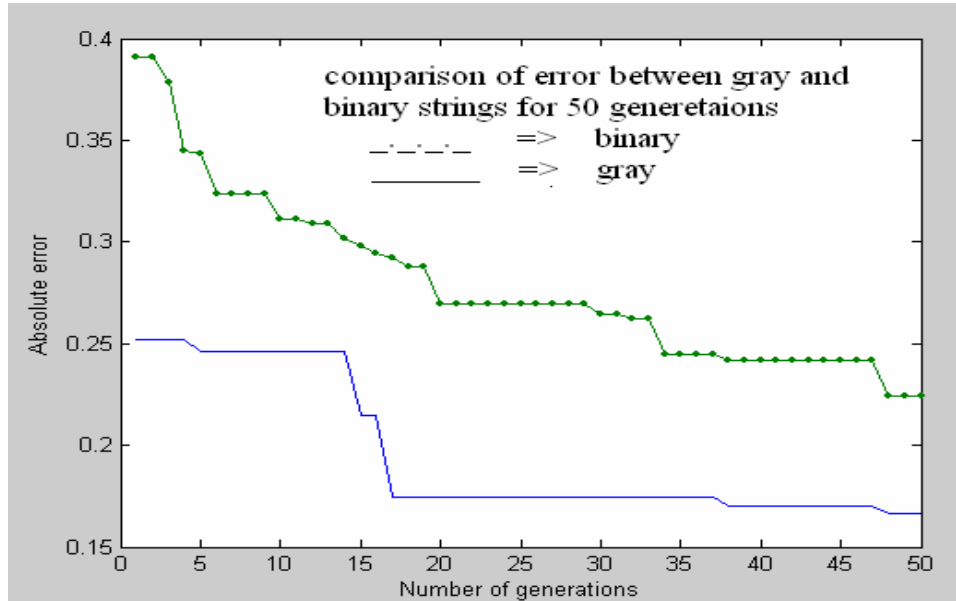


Fig. 10. Error comparison between gray and binary strings

In another work, synthesis of elliot pattern is done with analog genetic operators. A low error in the main lobe is obtained by this method.

Here, each chromosome is sorted in ascending order on the basis of the error due to its pattern deviation from desired pattern. The first 20 chromosomes are only taken into the mating pool. Two chromosomes are picked at random from the mating pool and crossover operation is done to obtain three offspring. This is done by considering the following linear combinations- $(u+v)/2, (3u-v)/1.5, (3v-u)/1.5$. The first combination gives the mid point while the other two give the extrapolation points thus widening the search space considerably.

Child chromosomes are mutated by selecting 2-3 elements and incrementing/decrementing both the real and imaginary parts of the excitation of the element. Here also, sectionwise optimization is adopted.

The crossover policy for the section wise optimization consists of adding all the elements if the two chromosomes are being added and multiplying only the corresponding section elements with the constant when the chromosome is being multiplied. The obtained radiation pattern has a 0.9572dB error in the main lobe and an average error of 5.72dB in the side lobe.

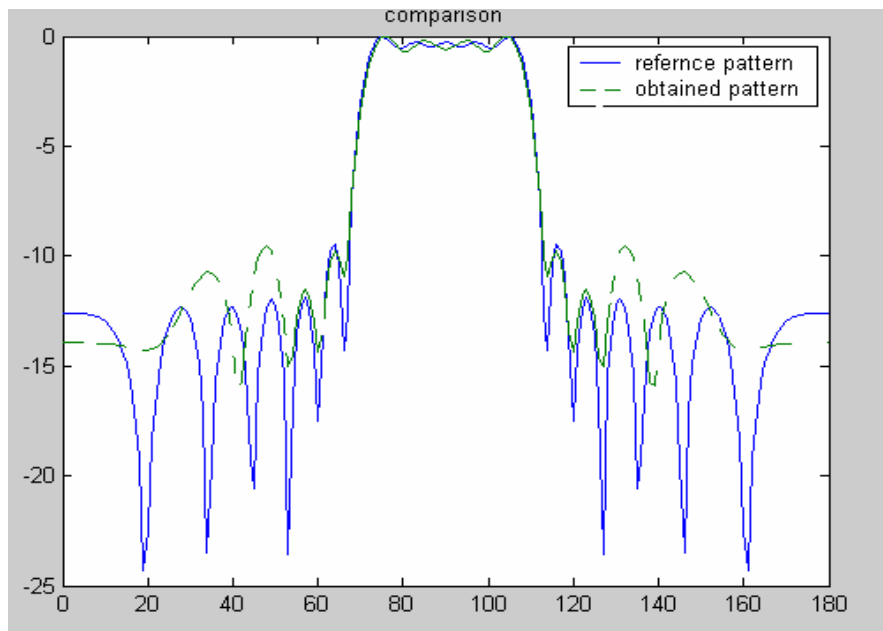


Fig. 11. Desired and Obtained patterns (Elliott's pattern) – Analog operators

Neural Nets:

There exists a myriad of neural computing architecture, classification procedures, application physical lay outs and parameterization. The proposed work uses the layered perceptron neural network architecture to process the desired operation for fault classification and isolation. A properly designed solid neural network classifier can offer attractive features such as robustness to noise and high classification accuracy. It is the selection of training and network architecture that determines the effectiveness of the network.

The selection of feed forward back propagation algorithm for classification of the patterns is done in this work, because of the inherent flexibility of this method and many

other advantages like small computing time etc needed for classification compared to conventional methods.

The radiation pattern values are given as input to the neural network to detect the fault in the array. It is best to perform the antenna diagnosis by measuring the radiated field with out removing the antenna array from its working site with out serious interruption of its operation. The faults that can be detected using neural networks are on/off faults, positional faults and phase shifter faults. Each fault is identified independently using a separate neural network.

To achieve the objective of locating faults, a feed forward back propagation neural network is initially trained with all possible faulty radiation patterns. Then, it is used to predict the fault by giving a test pattern to it.

The neural network has to be trained with a set of input output data pairs. The radiation pattern of the array with on/off faults is given as input to the neural network, the number of faulty element is obtained as output. In positional faults case, the complex radiation pattern at a particular angle where the error is more is given as input to the neural network. The error in distance is obtained as out put for the faulty element. In phase shifter fault the error pattern is given as input to the neural network and the number the element with faulty phase shifter is obtained as output. To describe the pattern correctly a large number of samples are required and the number varies with the complexity of the pattern. A large number of samples require a large number of input nodes for the neural network. A large neural network is hard to implement and needs a lot of time for training. The output obtained is the number of positional fault in binary format.

With the present architecture, the results indicate that for 97%of all cases presented, the network showed the correct result i.e in on/off fault, the positional fault, phase shifter fault. The results are presented in a confusion matrix. Attempts are being made to detect the faults in current amplitudes following the same procedure.

References:

1. "Shaped Beam Radiation Pattern Synthesis Using Genetic Algorithms", Presented at International Conference on Electromagnetic Interference and Compatibility (INCEMIC-97), held at Hyderabad, India during Dec3 -5, 1997.
2. "GA Approach for Multilook Beam Synthesis", Presented at International Conference on Electromagnetic Interference and Compatibility (INCEMIC-99), held at New Delhi, India during Dec6-8, 1999.
3. D.E. Goldberg, Genetic Algorithms, Addison Wesley Co.