Design and Optimization of Array Antennas using Artificial Intelligence

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Abstract**: *The configuration of any array antenna requires a set of very critical necessities and parameters. Some of these are frequently represented in terms of antenna parameters, such as radiation pattern, Gain or Directivity, Main Beam width, Side Lobe Length etc. In general, antenna requirements are specified for a set of frequencies or frequency band. This paper proposes a hybrid method using artificial intelligence to design and optimize the array antennas. Firstly, a linear array antenna is designed in matlab software. An error in tilt is introduced manually to the array elements. Considering this as a distortion in real time, this error is optimized using Artificial Neural Networks algorithms. The neural network works on the modelling and optimizing the antenna arrays, by functioning on the geometric parameters and by taking into account some predetermined criteria. Artificial Intelligence is the tool used to optimize the error since it is can generate the results very fast compared to any other different optimization algorithms. The results are simulated using Antenna tool box and Artificial Neural Network tool box in Matlab.***

Index Terms**: *Array Antennas, Artificial Neural Networks, Optimization.***

I. INTRODUCTION

Degradation in performance of an array antenna found due to the random errors or fluctuations in the tilt or angle of dipole element affect the characteristics of the array antennas [1] and results in Low Directivity, high Side Lobe Levels and in angle deviation. One of the main applications of these linear array antennas are found in Global Navigation Satellite System, where these errors or fluctuations continue for a long time and even a small error in the system immediately results in deviation from line of sight for reception of satellite information at the bottom station[2]. In several cases, the increase in the side lobe level causes the signal to go in the undesired directions and interferes with the other channels. This interference is anticipated to form a lot of severe issues. To rectify these errors, we have proposed a method named design and optimization of array antennas using artificial intelligence.

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Since there is always a possibility of fault element existence in the array which is one of the reasons for degradation in its performance, optimizing these errors using the artificial neural network algorithms are presented with the discussion of deviations found out with respect to the radiation patterns.

II. ARTIFICIAL NEURAL NETWORKS

Artificial neural networks (ANN) are the computing systems that are impressed by the biological neural networks which in turn that represent our human brains. An Artificial Neural Network relies on a set of connected nodes known as artificial neurons, which freely design the neurons in a human brain. Each connection, like the synapses (junction between two neurons) in a human brain, can transfer a signal from one neuron to another artificial neuron. An artificial neuron that receives any signal has the ability to process it and then signal the additional artificial neurons that are connected to it. [4] An artificial neuron communicates with the neighbors by weights and able to activate itself according to the received signal. An ANN consists of three layers. They are input layers, hidden layers, output layers. The Input nodes give the data from the outside world to the system and are as one alluded to as the "Input Layer". No calculation is performed in any of the Input nodes – they simply pass on the data to the hidden nodes. The Hidden nodes have no immediate association with the outside world (thus the name "hidden"). They perform calculations and exchange data from the input nodes to the output nodes. An accumulation of hidden nodes forms a "Hidden Layer". While a feed forward system will just have a solitary input layer and a solitary output layer, it can have zero or numerous Hidden Layers. The Output nodes are collectively considered as the "Output Layer" and are in charge of calculations and exchanging data from the system to the outside world.

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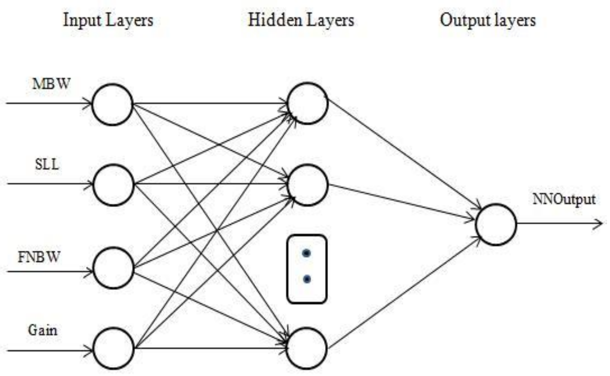

Fig.1 Representation of ANN model with 4 inputs & 1 output

In the above figure, MBW indicates Main Beam Width, SLL indicates Side Lobe Level, FNBW indicates First Null Beam Width, NNoutput represents the Optimized output.

III. WHY ARTIFICIAL NEURAL NETWORKS?

The long term of development has presented the human brain many required characteristics which are not included in the modern parallel computers [3]. They comprise of:

- massive parallelism
- distributed representation and computation
- learning ability
- generalization ability
- optimization ability
- fault tolerance and low energy consumption.

It is desired that the systems based on neural networks will exhibit these required characteristics.

IV. PROPOSED METHOD

Here we include several important factors in the use of artificial neural networks to optimize the design of array antennas. In general, an error function is defined to assess whether the proposed antenna meets the requirements or not. We have used Levenberg-Marquardt training algorithm of artificial neural networks to optimize our error included array antenna. The optimized output of the neural networks depends on the number of iterations. For every iteration the output varies as it thinks as a human brain and gives the output.

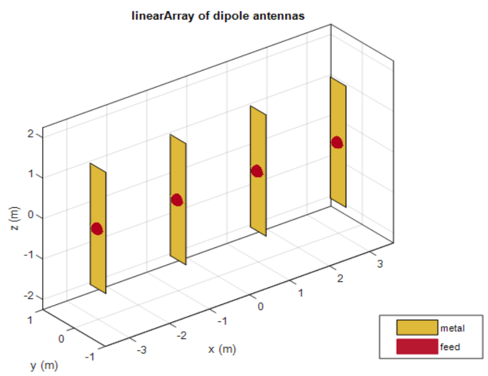

Fig.2 Layout of Linear Array Antenna

The figure 2 represents the layout of our linear array antenna consisting of four dipole elements of length 3m, width 0.5m with an element spacing of 2m. The phase shift and tilt of the above array antenna are 0 with TiltAxis [1 0 0].

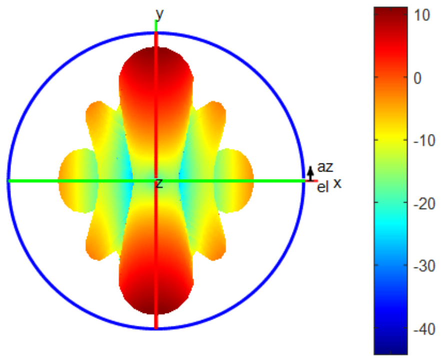

Fig.3 3D Radiation pattern of antenna in XY plane

The Fig.3 represents the 3D radiation pattern of the linear array antenna in XY plane at a frequency of 87MHz. It has a Directivity of 11.2 dBi. The Azimuth angles taken are in the range [-180°, 180°] and the elevation angles are in the range [-90°, 90°]. The Main Beam Width of the above figure is 32, SLL= -3.8426dB, First Null Beam width = 61.8283°.

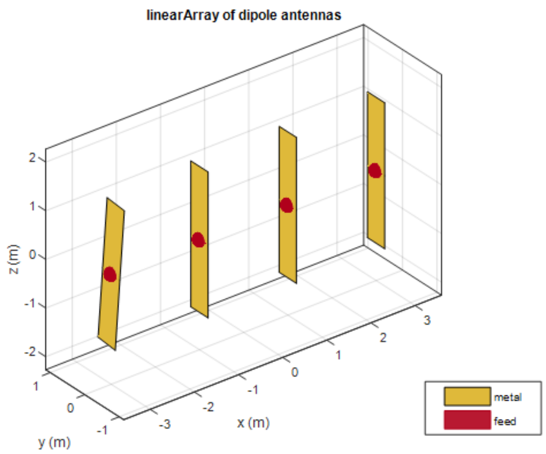

Fig.4 Layout of 5 degrees tilted antenna

The above figure represents the linear array antenna with an error in the tilt of 5° for the first dipole element. And all the remaining parameters are same as the Fig:2.

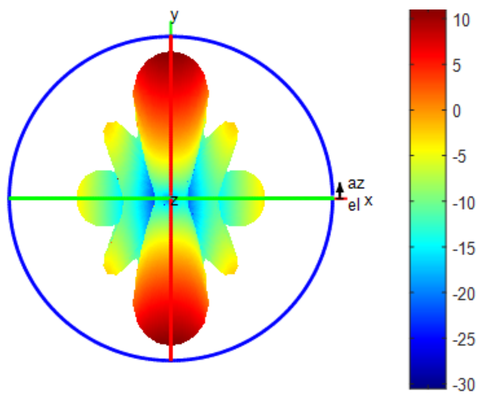

Fig.5 3D Radiation pattern of 5° tilted antenna in XY plane

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The above figure represents the 3D radiation pattern of the tilted linear array antenna in XY plane at a frequency of 87MHz. As there is an error there will be a change in all the parameters. Now the array antenna has a Directivity of 11.1 dBi. The Azimuth angles taken are in the range [-180°, 180°] and the elevation angles are in the range [-90°, 90°]. The Main Beam Width of the above figure is 32, SLL= -3.8226 dB, First Null Beam width = 61.8283°.

V. RESULTS AND DISCUSSION

The designed model of linear array antenna and its radiation pattern are simulated using Matlab 2018a software. The tilted array antenna which is having an error in some parameters when compared to the original antenna is optimized using Artificial Neural Networks tool box in the Matlab. The input data sets given to the neural network are Main Beam Width, Side Lobe Level, First Null Beam Width and Gain. Then we get an optimized radiation pattern.

Tilt	Main Beam Width			Side Lobe Level (dB)			First Null Beam Width			Gain(dBi)		
	True Value	Actual Value	Error	True Value	Actual Value	Error	True Value	Actual Value	Error	True Value	Actual Value	Error
5°	32	32	0	-3.842	-3.822	-0.02	61.828	61.828	0	11.2	11.1	0.1
10°	32	33	-1	-3.842	-3.738	-0.104	61.828	61.825	0.003	11.2	11.1	0.1
15°	32	34	-2	-3.842	-3.644	-0.198	61.828	61.825	0.003	11.2	11.0	0.2
20°	32	36	-4	-3.842	-3.538	-0.304	61.828	63.822	0.006	11.2	10.9	0.3
25°	32	37	-5	-3.842	-3.386	-0.456	61.828	65.817	-3.989	11.2	10.7	0.5
30°	32	40	-8	-3.842	-3.255	-0.587	61.828	67.811	-5.983	11.2	10.5	0.7
35°	32	43	-11	-3.842	-3.109	-0.733	61.828	129.63	-67.80	11.2	10.3	0.9
40°	32	47	-15	-3.842	-2.986	-0.856	61.828	129.63	-67.80	11.2	10.1	1.1
45°	32	52	-20	-3.842	-2.823	-1.019	61.828	131.63	-69.80	11.2	9.84	1.36
50°	32	59	-27	-3.842	-2.710	-1.132	61.828	131.63	-69.80	11.2	9.59	1.61

The above table represents the comparison of true values and actual values of several parameters for an error in tilt from 5 degrees to 50 degrees at a frequency of 87 MHz. As we can observe that as the error in the tilt increases the gain of the antenna decreases. As the gain value decreases the performance of the antenna also decreases. The Side Lobe level is expected to be more than the main lobe but if it is more than the major lobe, it is considered as degradation in the performance of an array. We can also observe that as the tilt increases above 30°, the first null beam width increases drastically. We have taken error upto 50° only because as the tilt varies more than 50 degrees the dipole tends to fall and in real time we find only slight errors in the tilt. Similarly, we can change the tilt in another direction also i.e, -5 degrees to -50 degrees.

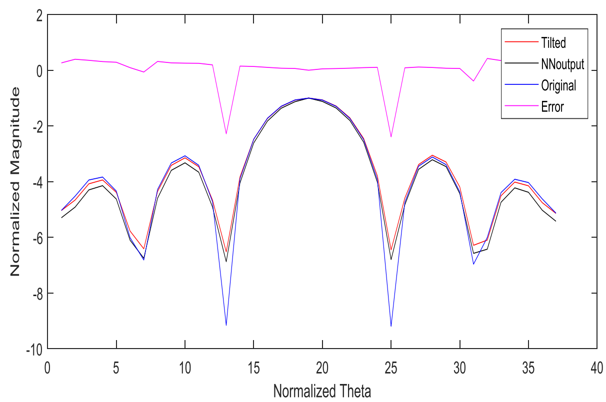

Fig.6 Final Optimized 2D Radiation pattern using ANN

The above figure shows the final output of our project i.e the optimization of the radiation pattern of the tilted array antenna using artificial neural networks. The blue color line indicates the true or original radiation pattern of linear array antenna with a tilt of 0 degrees.

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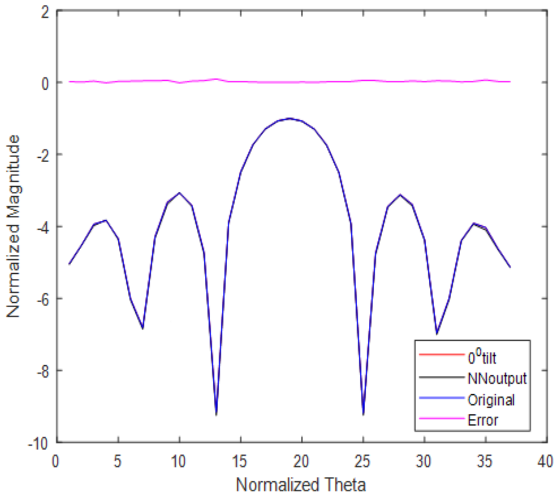
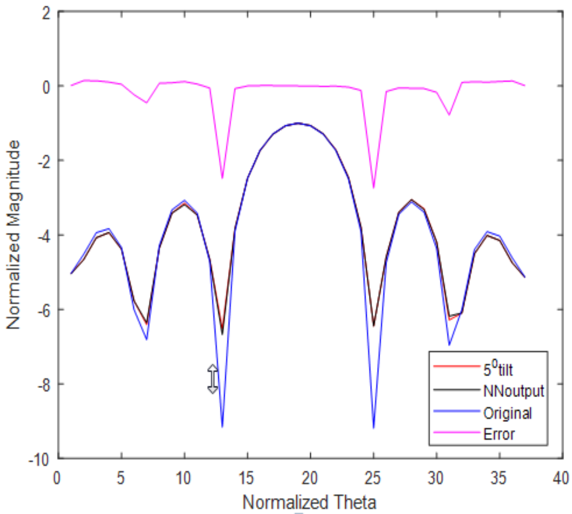
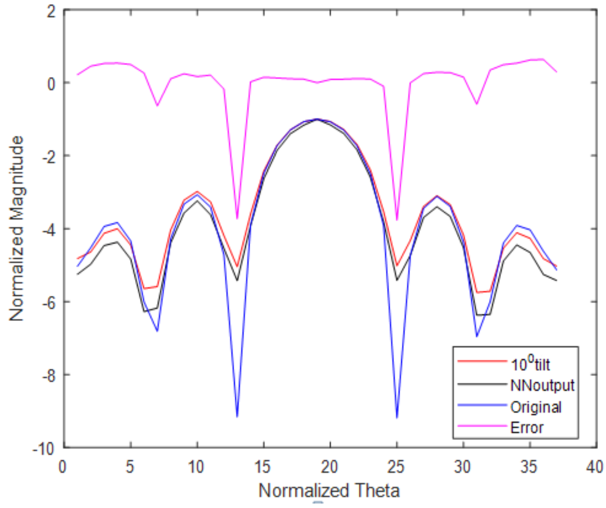
The red color line indicates the normalized 2D radiation pattern of 5 degrees tilted array antenna. The black color line indicates the NNoutput (Neural Networks output) i.e the optimized 2D radiation pattern of the tilted array antenna using artificial neural networks. The pink color line indicates the error between the true radiation pattern and the optimized radiation pattern. The number of iterations = 11 and the time taken for the simulation is 5sec. The simulations are done using Matlab 2018a software. For the optimization, Artificial Neural Network tool box is used in matlab. Simultaneously, the code is simulated for a range of tilts upto 50 degrees and all the corresponding graphs are shown below. From all the below figures, it is observed that the neural network is taking random iterations and simulation time for every simulation we run. But for a tilt of 50 degrees, it took the maximum numbers of iterations and maximum amount of time. All these simulation were done in Windows i5 configuration of 12 gb RAM.



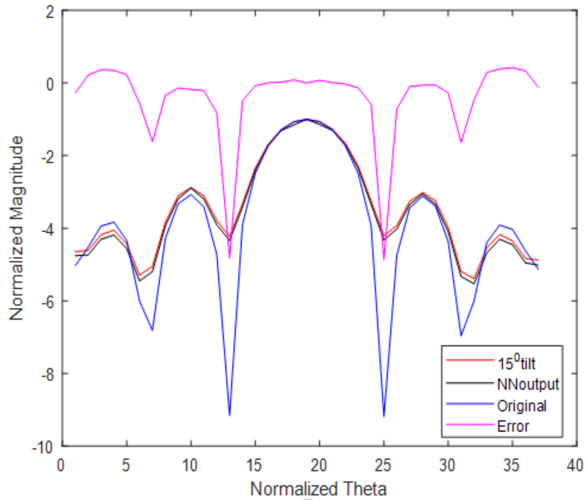
Number of iterations taken: 10
Total Simation time: 5 sec



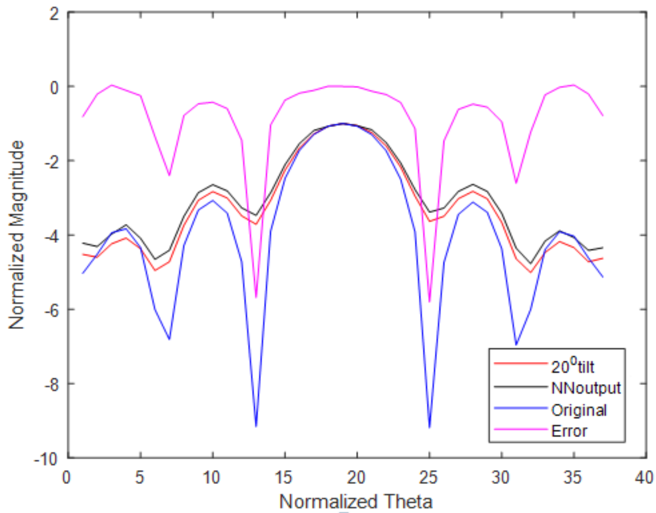
Number of iterations taken: 12
Total Simation time: 6 sec



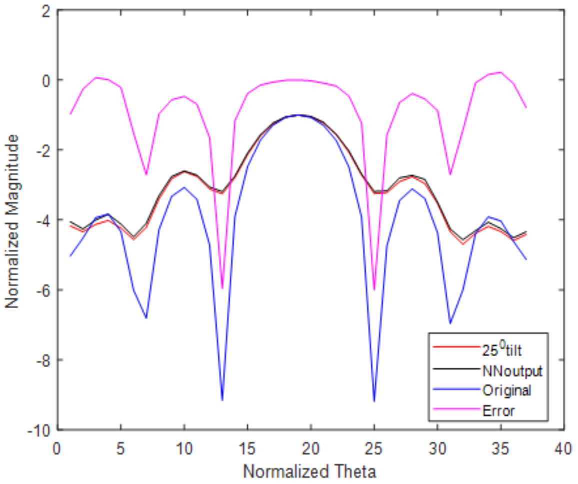
Number of iterations taken: 9
Total Simation time: 5 sec



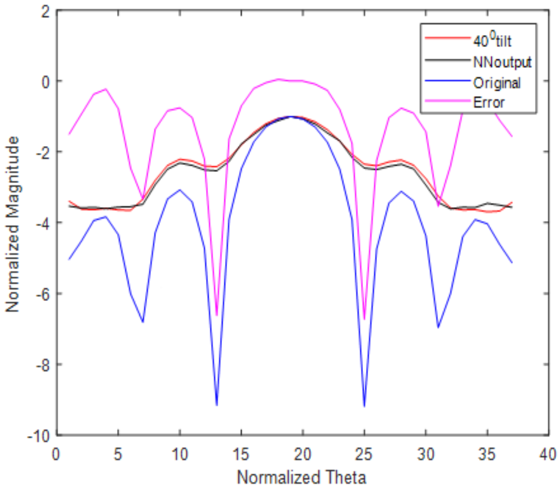
Number of iterations taken: 11
Total Simation time: 6 sec



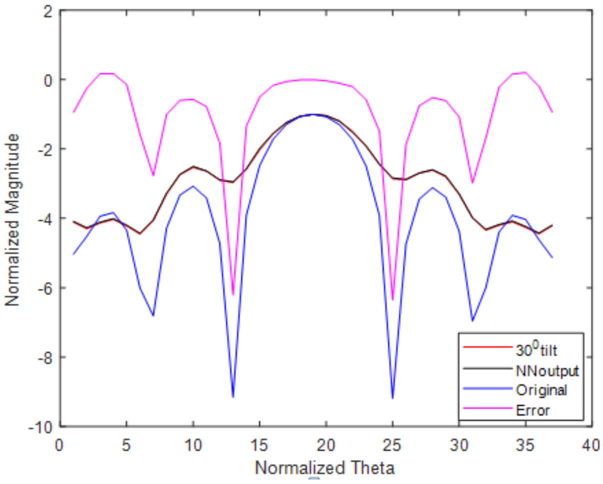
Number of iterations taken: 8
Total Simation time: 4 sec



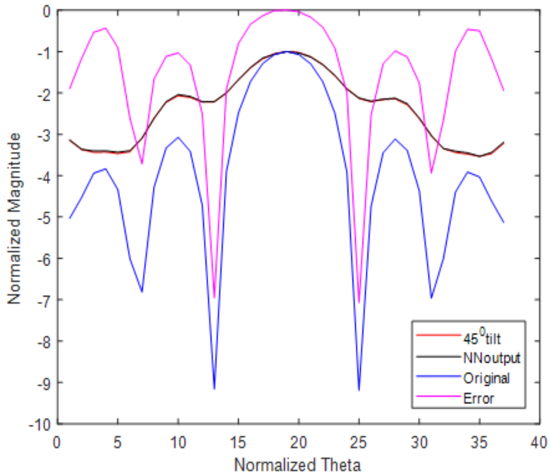
Number of iterations taken: 9
Total Simation time: 5 sec



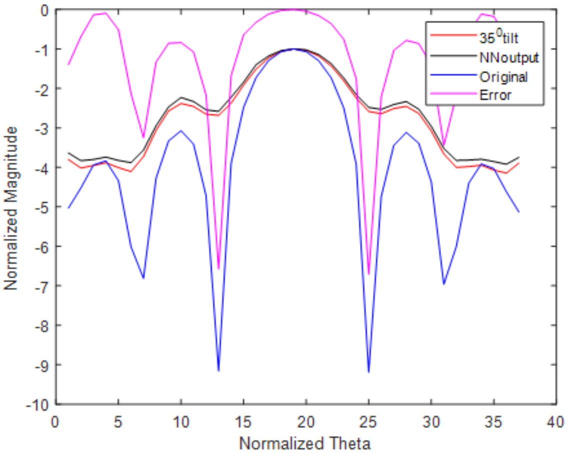
Number of iterations taken: 7
Total Simation time: 4 sec



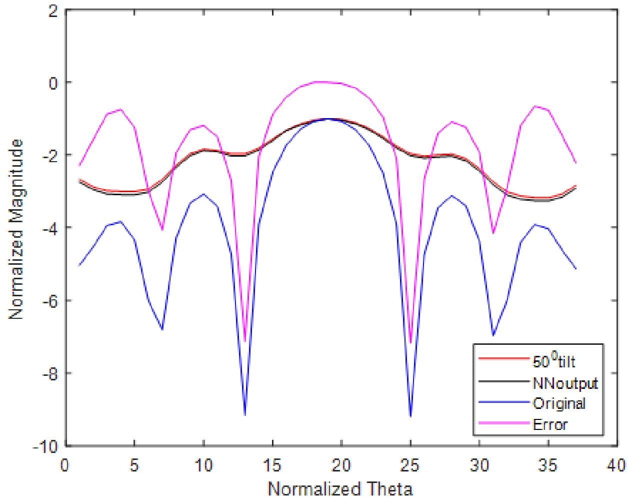
Number of iterations taken: 13
Total Simation time: 8 sec



Number of iterations taken: 8
Total Simation time: 4 sec



Number of iterations taken: 9
Total Simation time: 5 sec



Number of iterations taken: 29
Total Simation time: 15 sec

VI. SUMMARY

We have presented a hybrid method to design linear array antennas. The main aim of our paper is to optimize the errors in the radiation pattern of the antenna using artificial neural network algorithms. The first step includes design of linear array antenna. The second step includes introduction of error in the tilt of one dipole element in the antenna. For the antenna optimization we have used Artificial Neural Networks algorithm. This algorithm is applied to the inputs(MBW, SLL, FNBW, Gain) data sets of the array antenna to estimate and minimize the error towards an extent. A brief table on the comparison between the true values and actual values and the error is presented. It is observed that as the error increases the gain value decreases slightly which degrades the performance of the antenna. The error in the radiation pattern is optimized and plotted in a graph along with the original radiation pattern to know the error.

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