Neural network approach to diagnose phase shifter faults of antenna arrays

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Abstract - The diagnosis of faulty phase shifter in a uniform linear phased array antenna using a new method is presented. For parallel feeding of antenna elements each element has a separate phase shifter. The phase shifter for any particular element may fail due to failure in drive electronics. The failures of phase shifter are called phase shifter faults. In this work, an artificial neural network approach is adopted to diagnose phase shifter faults. A linear array of 21 elements with uniform spacing and uniform excitation with a progressive phase shift of Π is considered. A feed forward back propagation algorithm is used to train a neural network with a deviation radiation pattern which is the difference between the measured radiation pattern of array with normal phase shifters and degraded radiation pattern of array with a faulty phase shifter. The network thus trained predicted the number of the antenna element with faulty phase shifter with a high success rate. This is illustrated in a confusion matrix.

KEY WORDS

Uniform linear phased array, antenna radiation pattern, artificial neural network, feed forward back propagation, phase shifter faults, confusion matrix.

I INTRODUCTION

In uniform linear phased array antenna there exists a specific current phase relation ship between antenna elements. The individual antenna elements cooperate together to create a focused pattern of response. In uniform linear phased array antenna, there exists a progressive phase shift of α between the array elements. For parallel feeding of the antenna elements, a phase shifter introduces a phase shift of nα for each element separately. If any one of phase shifter fails due to ageing or due to failure of drive electronics or otherwise, it will introduce zero phase shift for that particular element, other phase shifters work normally. The failure of phase shifter in an antenna array is called phase shifter fault. These phase shifter faults degrade the radiation pattern of the array causing errors in related systems. Due to these faults the radiation pattern features like main lobe levels and side lobe levels change. These changes may be very much intolerable in many scenarios.

As an antenna array has several radiating elements, there is a high possibility of failure of any one of them. Locating the faulty phase shifter of an array is a complex problem. For an antenna array with several radiating elements and which cannot be brought to laboratory for inspection, the diagnosis of faulty phase shifter can be performed from measured degraded far field radiation pattern from its working site and without a serious interruption of its operation. In case of large earth based antennas where the far field radiation pattern measurements can be performed, this choice proves to be very convenient. The solution is based on the fact that if any phase shifter fault occurs, the overall radiation pattern would get affected.

Here, for the first time to the best of authors' knowledge neural network approach is used. The authors made an earlier presentation on the use of neural network for detection on–off faults positional faults[1],[2] of linear array. A smart solution to this problem of location of faulty phase shifter is to get initial radiation pattern without faults and degraded radiation pattern with any one faulty phase shifter. By observing the deviation between these two patterns with help of a neural network the faulty phase shifter can be detected.

A feed forward back propagation neural network is initially trained with all possible faulty radiation patterns. After training, it is used to predict the number of the element with faulty phase shifter.

II THE METHOD

Let us consider a linear array of N elements equally spaced and uniform excitation with a progressive phase shift of α (α=Π). It is assumed that there are N isotropic elements and N is an odd number N=2*M+1.

The array factor is written as

$$A(\Theta) = \sum_{i=-M}^{M} a_i \; e^{j\, i\, (k\, d\, \cos\Theta - \alpha)}$$

Where k is the propagation constant a_i the relative excitation of n^{th} element. For symmetrical excitation the pattern reduces to $a_i = 1$

$$A(\Theta) = \sum_{i=-M}^{M} e^{j\, i\, (k\, d\, \cos\Theta - \alpha)}$$

The reason for an odd number of elements taken is that, an odd number of elements produce a pattern whose average value over all angles is not equal to zero.

The radiation pattern of N element array with all elements functioning is determined. The faulty phase shifter introduces a phase shift of zero instead of nα, the degraded radiation pattern is determined with the expression

$$A(\Theta) = \sum_{\substack{i=-M \\ i \# r}}^{M} e^{j\, i\, (k\, d\, \cos\Theta - \alpha)} + e^{j\, r\, k\, d\, \cos\Theta}$$

III ARTIFICIAL NEURAL NETWORK

In its most general form, a neural network is a machine that is designed to model the way in which the brain performs a particular task or function of interest. The network is usually implemented using electronic components or simulated in software. The following definition of neural networks may be offered[3]. “A neural network is a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use. It resembles the brain in two respects (1) knowledge is acquired by the network through a learning process, and (2) interneuron connection strengths known as synaptic weights are used to store the knowledge”.

A neural network consists of many processing elements called neurons, each connected to many others. Every connection entering a neuron has a weight assigned to it. This weight is used to amplify, attenuate, and change the sign of the signal in the incoming connection. An input vector, containing the distinct input elements, is entered into the network. Each neuron operates on the outputs of other neurons connected to it according to its transfer function and delivers a single output. Often the transfer function sums the incoming signals to determine the value of the neuron’s next output signal. The result is an output vector representing some characteristics associated with the input.

If signals propagate in only one direction from an input stage through intermediate neurons to an output stage, then it is classified as feed forward network. The process of training the network is a matter of altering the connection weights systematically to encode the desired input output relationships. A supervised learning network adjusts weights on the basis of difference between the value of output units and desired values.

BACK PROPAGATION MODEL

Back propagation networks are multi layered, feed forward, neural networks that apply the error back propagation procedure for learning. The back propagation procedure uses the gradient descent optimization method, which adjusts the weight in its original and simplest form by an amount proportional to the partial derivative of the error function with respect to the given weight. The error back propagation is a typical supervised learning procedure. The learning procedure is as follows:

1. Initialize the weights of the network as small random values.
2. Start the learning cycle by exposing the network to a certain input pattern paired with the desired output.
3. Compute the network’s output and compare it with the desired output so that the error can be calculated.
4. Adjust the weights of the network using the error back propagation algorithm so that a certain amount of the detected error is removed.
5. Repeat steps, 3,4 with all the input patterns and their corresponding desired outputs, and compute the cumulative error.
6. If the cumulative error is within a tolerable range, terminate the training process, otherwise go back to step2.

NUMBER OF NODES

The network has to be trained with a set of input output data pairs. The complex deviation radiation pattern is sampled between angles from 0 to Π. 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. This is minimized initially.

IV RESULTS

To establish the validity of the procedure, a linear array with 21 isotropic elements with uniform excitation and uniform spacing is considered. The progressive phase shift between antenna elements is Π. The complex deviation radiation pattern is sampled between angles form 0 to Π for 11 values for faults in 21 elements. The deviation of pattern is very less in even numbered elements due to the phase shift introduced by those elements is an even multiple of Π and there is no fault in central element phase shifter as phase shift to be introduced is zero. The faults are determined for odd numbered elements i.e., for 10 faults. The samples are given as inputs to the neural network. The neural network consists of 22 input nodes one hidden layer with 11 nodes and 4 output nodes. The output of the neural network has a format b_3 b_2 b_1 b_0 where b_i can be any number between 0 to1. The output obtained is binary value of the number of the element with faulty phase shifter. Each neural network is trained with 10 test patterns. During the training it is observed that only 22 input nodes are sufficient. Using more input nodes leads to more accurate representation of the pattern but will also require a much larger network and hence the time. With the present architecture, the results indicate that for 98% of all cases presented, the network showed the correct result.

The obtained confusion matrix is presented below in table 1. The rows indicate the phase shifter fault given by the Neural Network and the columns indicate the exact phase shifter fault. Any entry Y in a particular box indicate the output given by the network for a particular input pattern with phase shifter fault.

V CONCLUSION

A new simplified technique for diagnosing phase shifter fault in uniform linear array is presented. This approach makes use of Neural Network that can be trained offline for any number of elements, spacing and excitation. Once the network is trained, it can detect the phase shifter faults with faulty pattern input.

The confusion matrix presented above clearly demonstrates high success rate of the Neural Network. Attempts are being made to improve the accuracy and reducing the complexity by adopting other types of algorithms as well as giving different inputs like Fourier coefficients of the faulty radiation patterns.

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Table.1- Confusion matrix

Number of Faulty phase shifter	1 (-9) element	2 (-7)	3 (-5)	4 (-3)	5 (-1)	6 (1)	7 (3)	8 (5)	9 (7)	10 (9)
1	Y									
2		Y								
3			Y							
4				Y						
5					Y					
6						Y				
7							Y			
8								Y		
9								Y		
10										Y