Using Neural Networks for Switch Failure Correction in Frequency Reconfigurable Antenna Arrays

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***Abstract*—This paper presents a new technique to correct switch failures in a frequency reconfigurable antenna array. The correction procedure requires at the beginning a detection of the failed switch. The detection process relies on integrating sensing lines within the array substrate to monitor the switch failure. The proposed correction technique is based on using Neural Network (NN) to overcome the failed switch. This is achieved by making the trained NN searches for other switch combinations that give the same array behavior.**

I. Introduction

Reconfigurable antenna arrays are proven to provide lot of advantages for wireless communications systems by improving the channel capacity and maintaining a good communication link. To achieve the required reconfiguration, switching elements such as RF MEMS or PIN diodes are integrated within the array [1]. Therefore, it is essential to introduce a switch failure detection methodology and more importantly to overcome such failure.

In this paper, we present a new technique to correct a failed switch in a frequency reconfigurable antenna array by using Neural Networks (NN). In section II, we briefly discuss the reconfigurable antenna array and its corresponding NN model. Section III details the correction procedure after performing the required training to the proposed NN model.

II. Neural Network Modeling For The Frequency Reconfigurable Antenna Array

The proposed antenna array is shown in Fig. 1. It consists of four identical square patches that are fed via a corporate feeding structure. Eight switches are included within the array structure where each square patch contains a pair of two switches. The location of the eight switches is labeled by a dotted circular shape in Fig. 1. Based on the status of the different switches, the antenna array is able to change its operating frequency.

In order to be able to correct any switch failure that can occur, it is essential to be able to first determine which switch has failed. From Fig. 1, one can notice that there are 2 ports for the vertical sensing lines and 2 ports for the horizontal ones. These sensing lines are integrated within the array substrate and are used to detect any switch failure. The detection of the corresponding failed switch is based on measuring the coupling between the horizontal and vertical lines. The appropriate sensing lines are chosen so that they pass underneath the patch that contains the failed switch. Any change in the coupling between the appropriate sensing lines allows determining the failed switch [2].

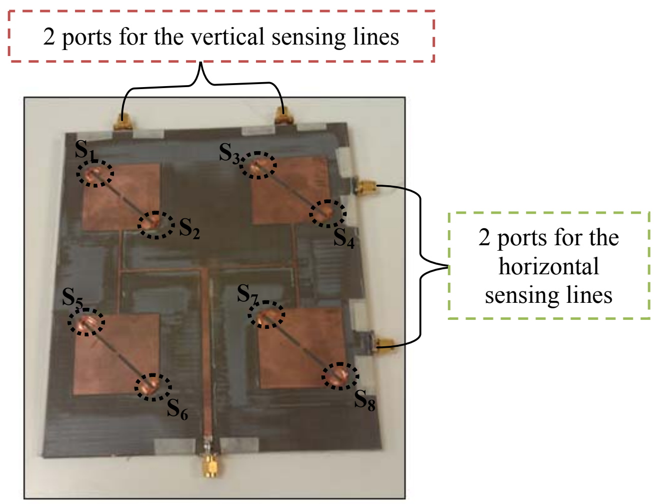

Figure 1. The frequency reconfigurable antenna array

The correction of the failed switch is done by training a NN after accomplishing the detection process. The correction is based on the idea that different switch combinations can give the same operating frequency while preserving the same radiation pattern and polarization. These different combinations are called equivalent configurations. Thus, the function of the trained NN is to determine at least one of the equivalent configurations that bypass the defected switch and maintain the same operating frequency for the array.

The NN architecture of the frequency reconfigurable antenna array under study, shown in Fig. 2, consists of three layers. The first layer is called the input layer (I/P) and is the only layer exposed to external signals. The input layer in this case consists of 299 input neurons which represent the minimum number of points required to represent the array's reflection coefficient. The second layer is called the hidden layer. Its function is to extract relevant features from the received signals at the input layer. The hidden neurons are optimized to 11 neurons. The third layer is the output layer (O/P). It consists of 8 output neurons which are equivalent to the number of switches integrated within the antenna array.

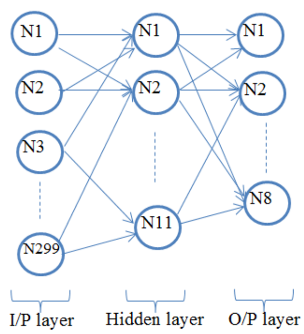

Figure 2. The NN modeling of the frequency reconfigurable antenna array

III. THE CORRECTION PROCEDURE

The training of the NN architecture discussed previously is based on searching for the appropriate equivalent configurations. Fig. 3 shows for example that the proposed reconfigurable antenna array resonates at f=3.65 GHz when S_1 and S_4 are ON. If S_4 fails, the array no longer operates at this frequency. By activating S_2 and S_3, the array is able to restore its operating frequency at f=3.65 GHz. Therefore, we can notice that the presented array has two equivalent configurations at f=3.65 GHz. These two configurations should provide the same radiation pattern and polarization as well to ensure an appropriate functioning for the reconfigurable antenna array in case S_4 fails.

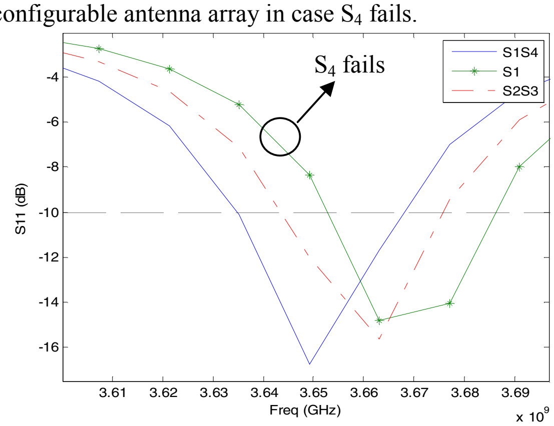

Figure 3. The equivalent configurations for the frequency reconfigurable antenna array at f=3.65

The NN model shown in Fig. 2 is built using MATLAB by providing to the neural network a set of the different reflection coefficients of the reconfigurable antenna array and the corresponding switch combinations. The neural network is trained until the mean square error (MSE) at the output reaches the stop value of 10^{-5}. This value of the MSE ensures that an appropriate weight connection between the different neurons of the NN has been achieved. Fig. 4 shows the number of iterations needed for the training process versus the MSE. It was found that the reconfigurable antenna array under study requires 11 iterations in order to achieve the required MSE. Therefore, the training is stopped at the iteration number 11.

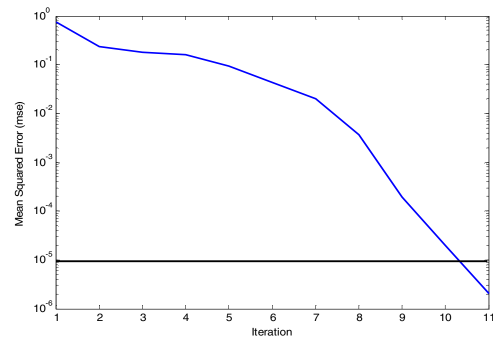

Figure 4. The minimum square error for the trained NN of the frequency reconfigurable array

The NN developed for the reconfigurable array is embedded into a field programmable gate array (FPGA) using Xilinx System Generator blocks. The advantage of this technique is that the FPGA now software controls the whole process of correcting any switch that has failed. This process is divided into the following steps:

Step 1: Determine the failed switch by investigating the coupling between the different integrated sensing lines of the reconfigurable antenna array

Step 2: Once the failed switch has been identified, the corresponding reflection coefficient for the reconfigurable antenna array should be provided to the NN that is embedded into an FPGA. The NN then determines the appropriate equivalent configuration. The FPGA will accordingly automate the corresponding switches by providing the needed voltage or current level to the switches.

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