Detection of the Faulty Sensors on Basis of the Pattern Using Symmetrical Structure of Linear Array Antenna

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Abstract ─ In this paper, a simple method is proposed to diagnose the position of the damaged sensors. The position of the damaged sensors is diagnosed on the basis of the null depth level and the number of nulls for the degraded radiation pattern. The method is initiated with tabulation of the array radiation pattern with a single damaged sensor. The corresponding pattern is set as the reference to the radiation pattern of the failed sensors. The tabulated damaged array sensors are compared to a configuration of the assumed damaged sensor. The radiation pattern with deeper null depth level will be the location of the damaged sensor. Moreover, the symmetrical sensor damaged (SSD) technique diagnose the position of damaged sensor, in which on the basis of nulls one can detect the location of damaged sensors. The proposed method diagnoses the location of damaged sensors on the basis of pattern without complex computation as compared to available methods.

Index Terms ─ Array antenna, fault detection, null depth level, nulls.

I. INTRODUCTION

Detection of the damaged sensors in a phased array antenna is an important research topic for radar, satellite and microwave [1-5] applications. The array antenna with a large number of radiating sensors has the possibility of getting the failures for at least single unit of sensors. The sensor failures, damages the peak sidelobes level (PSL) and nulls [6-8]. To ensure the performances of array antenna are conformed to the desired requirements, failure sensors have to be detected regularly [9] and correction must be attempted [10-11]. Detection of the damaged sensors in an array antenna is unarguably the main task to be addressed in array testing [12-18]. Correct diagnosis of the damaged sensors for a large array antenna is a big challenge in both theoretical and algorithm point of view. Several available techniques in the literature to diagnose the position of the damaged sensors from the measurement of healthy and the degraded radiation power patterns [19-25]. Several techniques had been proposed such as the genetic algorithm [26], back propagation algorithm [27], matrix method [28], exhaustive searches [29], MUSIC [30], compressed sensing as well as Bayesian compressive sensing (BCS) [31-32]. Recently, Zhu et al. [33] proposed a method which does not requires a priori knowledge of the malfunctioning sensors and permits some sensors with complete failure. Fuchs et al. [34] has developed a fast diagnosis of the array antennas from a small number of far-field measurements which requires a priori knowledge of the reference array power pattern. This method uses the sparse recovery algorithms to diagnose the damaged sensor positions from a small number of measurements. However, the aforementioned diagnosis of damaged sensors requires a complex computation for each of the configuration of the array factor.

The symmetrical linear array is of great importance and has many advantages. In [35-36], the symmetrical element failure (SEF) gives better null depth level (NDL), while in [38] it requires half of the damaged pattern for the damaged sensor detection as compared to [37]. In [39], a linear symmetrical array antenna is used for failure correction, where the failed sensor signal is reconstructed from the symmetrical counterpart sensor by considering its conjugate. In this paper, a simple approach for the diagnosis of array antenna on the basis of the null depth level and nulls of the degraded far-field radiation power pattern is described using a linear symmetrical array. The method tabulates the radiation pattern of the array with single damaged sensor. Then, the corresponding radiation pattern the configuration of failed sensors under test is checked with the configuration of the damaged sensor. The radiation pattern with a deeper null depth level will be the location

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of damaged sensor. The symmetrical sensor damaged (SSD) technique is used for the diagnosis of the damaged sensor, in which on the basis of the nulls one can detect the location of damaged sensors. This article is organized as follows. The problem formulation is described in Section 2, while Section 3 describes the proposed methodology of detecting the damaged sensors. Subsequently, Section 4 presents the simulation results of the proposed method. Finally, the conclusion is made in Section 5.

II. PROMLEM STATEMENT

Consider a linear reference array of $2K+1$ number of sensors with far-field radiation pattern is given by [40-41],

$$AF(\theta_i) = \sum_{n=-K}^{K} w_n \exp\big(jn(kd\cos\theta_i)\big), \tag{1}$$

where w_n is the weight vector of the reference array, k is the wave number $2\pi/\lambda$ and d is the distance between the antenna sensors. The degraded far-field power pattern of an array can be found using Equation (1) by making the weight excitation of that sensor equals to zero. The power pattern radiated by the degraded array can be identified by eliminating the weight excitation corresponding to the damaged sensors from the Equation (1). Furthermore, the degraded far field radiation pattern for the mth sensor damaged is given by the following expression:

$$AF_m(\theta_i) = \sum_{\substack{n=-K \\ n\neq m}}^{K} w_n \exp\big(jn(kd\cos\theta_i)\big). \tag{2}$$

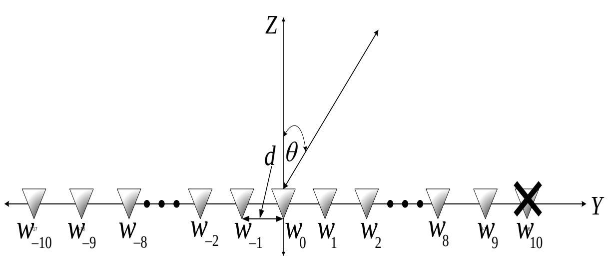

Fig. 1. Linear symmetrical array of $2K+1$ number of sensors with w_{10} sensor damaged.

Assume that the sensor, w_{10} in the array is damaged as shown in Fig. 1. The main objective is to detect the locations of the damaged sensors. Numerous techniques are found in the literature that diagnoses the locations of the damaged sensors. However, none of them is able to diagnose the damaged sensor locations on the basis of the radiation power pattern. The power pattern for the w_{10} sensors damaged is shown in Fig. 2 by the red solid line.

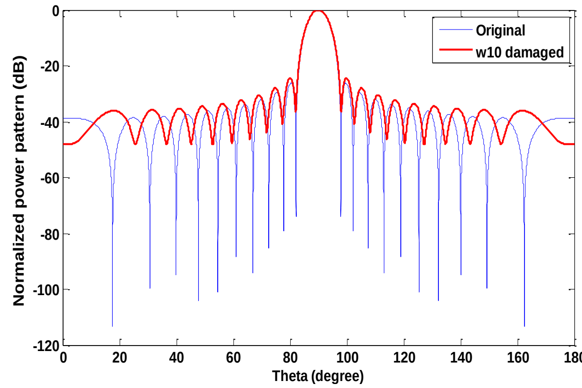

Fig. 2. Linear symmetrical Taylor pattern radiated by 21 sensors with w_{10} sensor damaged.

III. PROPOSED METHODOLOGY

The proposed methodology to diagnose the locations of the damaged sensors is based on the deeper null depth level and the number of nulls. As assumed for the damaged of w_{10} sensor, the null depth level is lost as depicted in Fig. 2. The pattern of w_{10} damaged sensors is then compared with the available damaged patterns. After comparing with the available damaged patterns, the symmetrical counterpart of w_{10} as shown in Fig. 3 will give a deeper null depth level, i.e., symmetrical sensor damaged (SSD) of w_{10} will give deeper nulls as shown in Fig. 4. Moreover, SSD technique predicts the location of the damaged sensors on the basis of the nulls. As the damaged sensors get nearer to the center of the array, the number of nulls reduces. If D represents the set of damaged sensors, i.e., all the possible patterns for a single damaged sensor. The degraded far-field power pattern of a set of D damaged sensors can be obtained by excluding the weight of the damaged sensor from the Equation (1) as shown in Equations (3) and (4):

$$AF_D(\theta_i) = AF(\theta_i) - \sum_{n\in D} AF(\theta_i), \tag{3}$$

$$AF_F(\theta_i) = \sum_{\substack{n=-M \\ n\notin D}}^{M} AF(\theta_i). \tag{4}$$

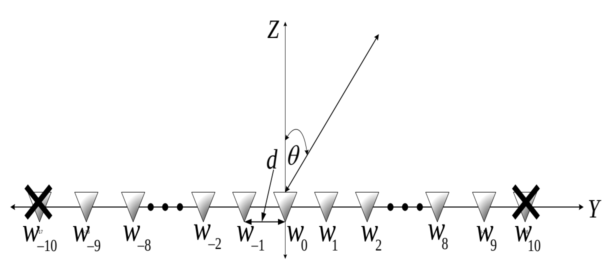

Fig. 3. Linear symmetrical array of $2K+1$ number of sensors with w_{10} SSD.

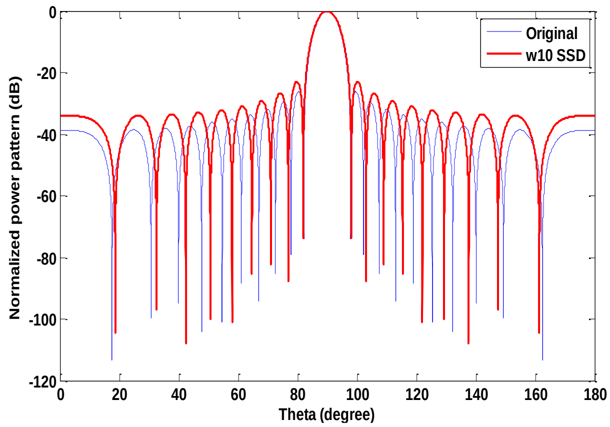

Fig. 4. Linear symmetrical array of 21 number of sensors with w_{10} SSD.

Assume that the number of patterns, radiated by the array with a known single damaged sensors. $\{AF_D(\theta_i)\}_{n=-K}^{K}$ is the $2K+1$ number of available damaged sensor patterns and $AF_m(\theta_i)$ is the pattern of the mth damaged sensor assumed to be failed. The method of detecting the damaged sensors in array antenna starts with the measurement of the damaged sensors pattern in θ_m direction. Then, the cost function C compares the damaged patterns with a given configuration of the failed sensor as shown in Equation (5). The cost function which gives the deeper null depth level will be the location of the damaged sensors, i.e., the symmetrical counterpart sensor will give a deeper null depth level:

$$C = \sum_{m=1}^{M} \left| AF_m(\theta_i) - AF_D(\theta_i) \right|^2 . \tag{5}$$

Firstly, the w_{10} SSD gives a deeper null depth level which allows the sensors position to be easily detected. Secondly, the number of nulls for w_{10} SSD is 18 which is reduced by 2.

IV. SIMULATION RESULTS

In this section, consider a linear symmetrical array composed of 21 number of sensors which are placed symmetrically from the origin along the x-axis. Analytical procedure [42] is used for the healthy set-up to radiate in the direction of $\theta = 90^\circ$ with sidelobe level of -30 dB. The radiation power pattern, shown in Fig. 5, has been created by taking a linear Taylor distribution with SLL=-30 and $n = 6$. So, there will be 20 number of nulls and one main beam for this healthy set up as shown in Fig. 5 by the blue solid lines. The number of nulls reduces as the sensors in the array become damaged near the centre of the array. At the first instant, it is assumed that the sensor w_9 become damaged in the array. The pattern of damaged sensor w_9 damaged is shown in Fig. 5 by the red solid line. To detect the pattern of the damaged sensor w_9 all the available damaged patterns, i.e., $\{AF_D(\theta_i)\}_{n=-K}^{K}$ are compared. The cost function in Eq. (5) is then compared for a given configuration of all the available damaged patterns and the sensor is assumed to be damaged. i.e., w_9. After comparison, the SSD of w_9 gave a deeper null depth level. The technique proposed in this article which uses Eq. (1) to tabulate both of the healthy power pattern as well as the one damaged pattern calculated at all the directions of the given samples. The computation of cost function in Eq. (5) for a particular configuration of the damaged sensors is very fast, because it requires using the available damaged patterns in Eq. (4) and the pattern of the assumed failed sensor only. This simple methodology will improve the computational cost as compared to the available techniques. Moreover the SSD technique is able to diagnose the location of damaged sensors without the needs of complex calculation. On the basis of the number of nulls of the degraded patterns, the position of the damaged sensors can be easily detected. For w_9 SSD, the pattern achieves deeper null depth level. Therefore, our decision is to diagnose the positions of the damaged sensors on the basis of null depth level and nulls. In this case, the number of nulls for w_9 SSD is 16. The number of nulls is reduced by 4 if w_9 SSD is occurrig as shown in Fig. 6. In the simulation results, a total of M=16 number of samples with no measurement error is considered.

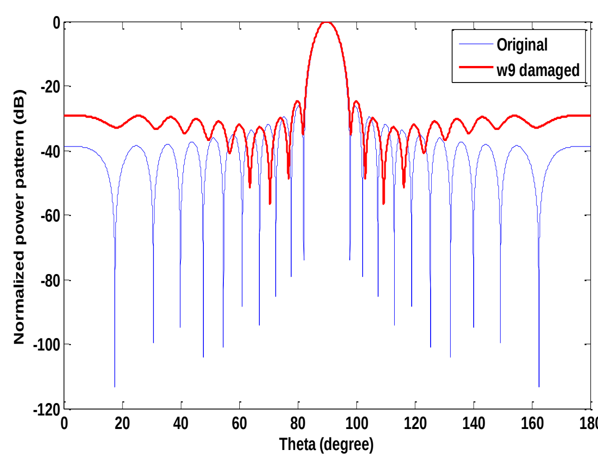

Fig. 5. Linear symmetrical Taylor pattern radiated by 21 sensors with w_9 damaged sensor damaged.

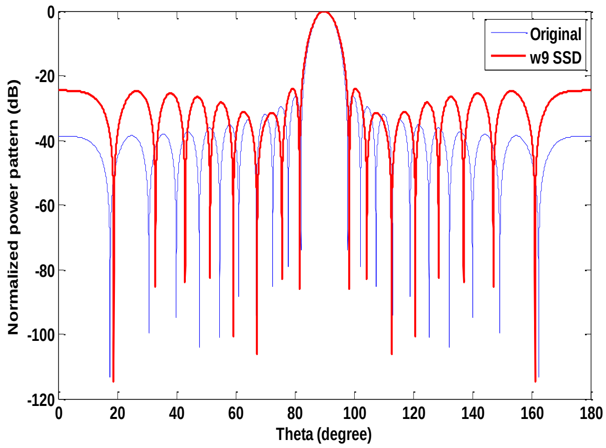

Fig. 6. Linear symmetrical array of 21 number of sensors with w_9 SSD.

The same procedure is repeated to diagnose the location of the damaged sensor w_8. The w_8 sensor pattern is compared with a given configuration of the available damaged pattern and then the cost function in Eq. (5) gives a deeper null depth level with w_8 SSD as shown in Fig. 7. At the same time, the number of the nulls for w_8 SSD is reduced by 6 and it is shown in Fig.7. Now, if the w_7 sensor is damaged in an array of 21 number of sensors, pattern of damaged sensor w_7 is compared with the given configuration of the available damaged pattern in cost function Eq. (5). Again, the w_7 SSD gives a deeper null depth level as depicted in Fig. 8

Moreover, the number of nulls for SSD is 12 which is reduced by 8. Therefore, the position of the damaged sensors can be easily detected from the degraded patterns on the basis of null depth level and number of nulls. From Table 1, it is obvious that if the damaged sensors gets nearer to the center of the array, the nulls are reduced by 2. For w_6 SSD, the number of nulls is 10. For w_5 SSD, the number of nulls is 8. For other following cases, the number of null has decreased by 2 as seen in Table 1. This symmetrical changes of number of nulls in the array radiation pattern is of great interest for the researcher.As one can see from Fig. 2, due to a single failure sensor one can not decide which sensor is damaged. On the basis of the SSD technique, the sidelobes level also conforms the diagnosis of the damaged sensors. From Fig. 4 and Fig. 6 it is clear that for w_9 SSD, the sidelobes level is higher than w_{10} SSD. Similarly, the sidelobes level for w_7 SSD is higher than w_8 SSD. From the simulation results it is clear that as the damage SSD nearer to the center of the array, the sidelobes level is increases while the number of nulls is reduces.

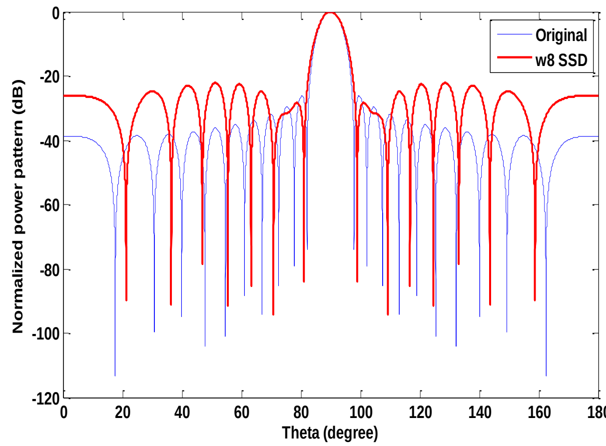

Fig. 7. Linear symmetrical array of 21 number of sensors with w_8 SSD.

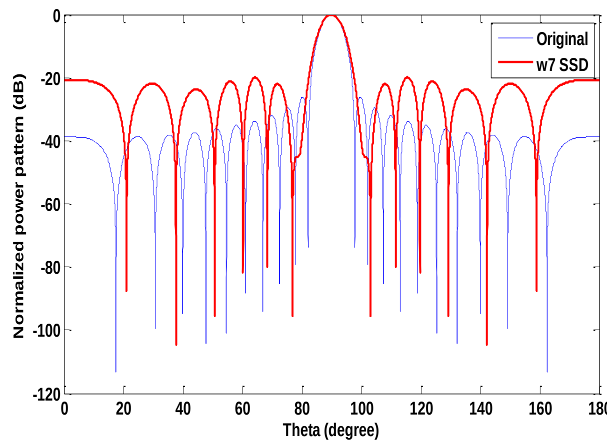

Fig. 8. Linear symmetrical array of 21 number of sensors with w_7 SSD.

Table 1: Detection of damaged sensor on the basis of number of nulls

Symmetrical Sensor Samaged (SSD)	Number of Nulls
w_{10}	18
w_9	16
w_8	14
w_7	12
w_6	10
w_5	8
w_4	6

In this case the performance of the proposed method is compared with the conventional method [37-38]. In [37], the main goal is to diagnose the location of faulty sensors using bacteria foraging optimization (BFO) technique. Let us consider a linear array of 21 number of sensors. The damaged patterns were generated by making their weights equals to zero. We considered that the 3rd, and 19th sensors are damaged in an array of 21 number of sensors. For the detection of 3rd and 19th failure we require $\sum_{f=1}^{2}\frac{N!}{\left[f!(N-f)!\right]}=210$ number of different patterns by the conventional method [37], while the method [38] requires 105 number of patterns for the same scenario of the damaged sensors. But our proposed method requires no computation, just on the basis of radiation patterns and number of nulls one can decide the location of the damaged sensors. The damaged array pattern obtained by the conventional method [37] as depicted in Fig. 9 while the performance is shown in Fig. 10. The same faulty scenario is diagnosed by [38] with half the number of samples poaints as shown in Fig. 11 and Fig. 12.

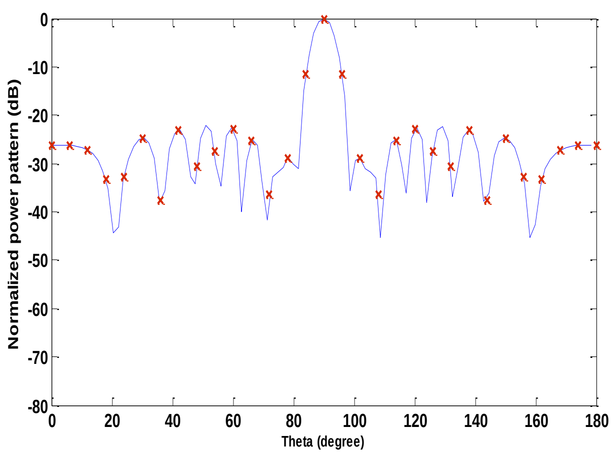

Fig. 9. Damaged array pattern with fault at 3rd and 19th sensors with 31 samples.

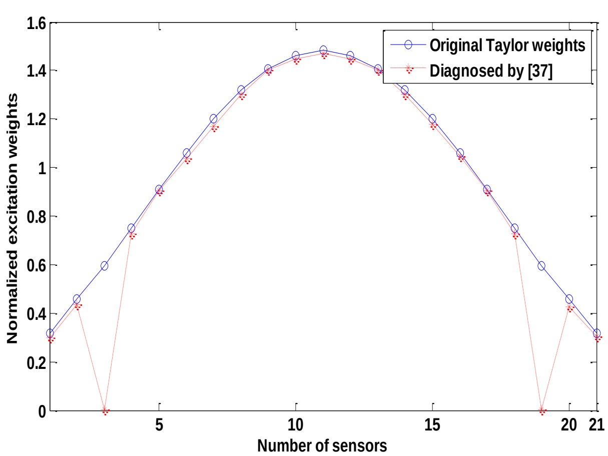

Fig. 10. Performance of the conventional method [37] with 31 samples.

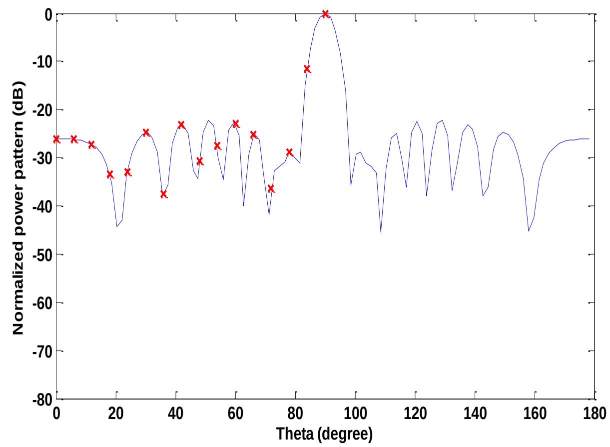

Fig. 11. Performance of the conventional method [38] with 16 samples.

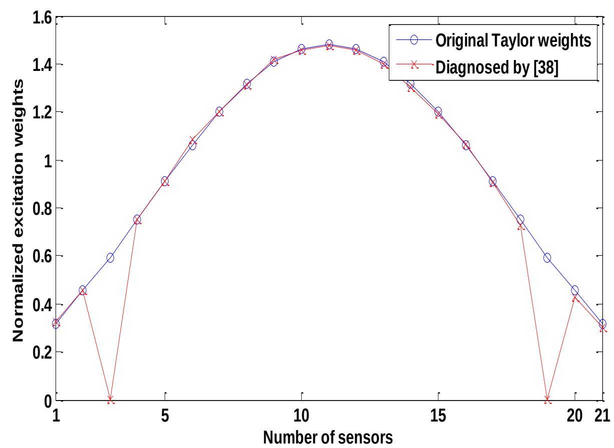

Fig. 12. Performance of the conventional method [38] with 16 samples.

V. CONCLUSION

In this paper, a simple approach of the damaged sensor detection in an antenna array on the basis of the deeper null depth level and nulls have been proposed. By using this approach one can easily detect the location of damaged sensors on the basis of degraded far-field radiation pattern. From the simulation results, it is observed that if the damaged sensors nearer the center of the array, the number of the nulls are decreases by 2. From this observation, it is a valid problem for the researcher and hence the number of nulls reduces as the damaged sensors get closer to the center of array. This approach is directly applicable to the L-type and circular arrays.

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