ROBUSTNESS OF A CORRECTION METHOD APPLIED TO A VERTICALLY DEFORMED HFSWR ON BUOYS

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***Abstract*—This paper presents two correction methods for vertical deformations of the receiving array belonging to HFSWR on buoys. The method inspired from Schelkunoff's representation is more robust to the deformation's uncertainty problem.**

I. INTRODUCTION

The concept of the Economic Exclusive Zone (EEZ) finds roots from the United Nations Convention regulations on the sea [1]. The EEZ is spread on a maximum of 200 nautical miles (370km) from the coasts. In this area, the state has sovereign rights that extend from the waters above the seabed and the seabed in the subsoil. The rights apply to the exploration and the exploitation of the zone for economic and military purposes, such as the production of energy from water, sea currents, winds, oceanographic parameters and target detection. High Frequency Surface Wave Radar (HFSWR) is one of the optimum solutions in order to monitor the EEZ. It uses a particular mode of propagation, the surface wave mode that propagates at the interface between the air and the sea. It is therefore possible to produce systems for permanent coverage with ranges of a few hundred kilometers. However, the receiving array requires a large space to have a good azimuthally resolution. This large space may not be provided by most countries that are already limiting the number of antennas in the receiving array. Thus, placing the antennas of the receiving array on independent buoys on the sea surface is the proposed solution in this paper as the available space is not limited. Unfortunately, this alternative solution also generates new problems.

The receiving array consists of N antenna elements. Each of them is supported by a floating buoy on the sea surface. The global radiation pattern of the receiving array results from a combination of all the element radiations. The main concern is the effect of the sea motion: each independent buoy (thus, each antenna) has its own movement, on the sea surface. As a result, the initial array arrangement will be modified continuously resulting in a continuous deformation of the global radiation pattern, Fig. 1. In this paper, the vertical deformation of the receiving array, its consequence on the mutual coupling and the associated perturbation in the radiation pattern are studied. We discuss and compare the corresponding correction methods and we prove the robustness of a correction method inspired from Schelkunoff's representation.

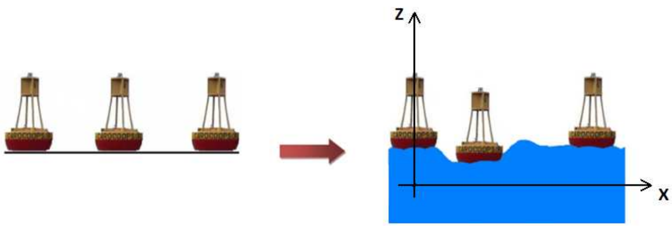

Figure 1. Deformation of the studied array.

II. VERTICAL DEFORMATION

A. *Coupling definition*

In a vertical displacement [2], there is no physical deformation in the observation plane (xOy), so the main disturbances come from the modification of the mutual coupling in the array when dipoles move vertically. Although these disturbances are usually small, they can be corrected easily. In an array of dipoles, mutual coupling takes place between elements. Using the conventions presented in Fig. 2, this mutual coupling is defined by the Z^{MU} matrix. For instance:

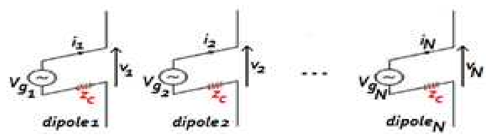

Figure 2. Representation of the studied array.

$$Z_{2k}^{MU} = \left.\frac{v_2}{i_k}\right|_{\substack{i_k \neq 0;\\ in=0\\ n\neq k}} \qquad n, k = 1, \dots N \tag{1}$$

Let $I = [i_1, i_2, \dots, i_N]^T$ be the currents in the antenna ports that produce the desired radiation pattern. The impressed voltages $V_g = \left[v_{g1}, v_{g2}, \dots, v_{gN}\right]^T$ can be defined as:

$$V_g = (Z^{MU} + Z_c I_d) I \tag{2}$$

where Z_c is the source impedance, Z^{MU} is the impedance matrix (representing coupling) and I_d is the identity matrix.

B. Consequence of the vertical deformation on the mutual coupling

In this subsection we will study the consequence of the vertically displaced antennas supported by floating buoys on the mutual coupling over the array. We begin by defining the current expression and the positions of the elements. Let Δv_k be the vertical displacement of antenna k with respect to antenna 1, Fig. 3.

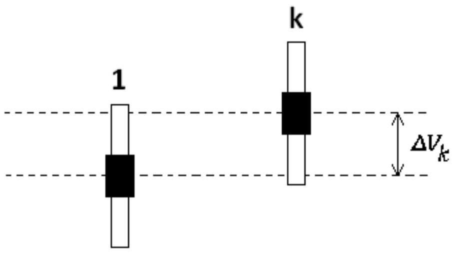

Figure 3. Parallel dipoles.

Instead of studying the evolution of Z^{MU}, we prefer to consider the evolution of the electric current's magnitude at the middle of the dipole. For clarity, we adopt a normalized representation of the currents. The reference value I^{ref} is the current on the central dipole of a uniform array with uniform excitation. The normalized currents are defined as:

$$i_n = \frac{I_n}{I_{ref}} \tag{3}$$

where I_n is the actual current on dipole n.
The antennas positions are defined as follows:

$$\tilde{x}_n = x_n \tag{4}$$
$$\tilde{y}_n = y_n \tag{5}$$
$$\tilde{z}_n = z_n + (2r_n - 1)\Delta v_{max} \tag{6}$$

where $\Delta v_{max} = 0.25\lambda$ is the maximum vertical deformation taken in our case, $(\tilde{x}_n, \tilde{y}_n, \tilde{z}_n)$ and (x_n, y_n, z_n) are respectively the coordinates of antenna *n* in the deformed and uniform array. R = $[\, r_1, \dots, r_N \,]$ is a random vector with each r_n defined as a uniform variable in [0, 1]. Then we consider the mutual coupling between N dipoles having a length equal to λ/2. The typical inter element spacing we use is λ/2 so the mutual impedance cannot be neglected [3]. The investigation is based on an array of 10 elements. The deformation effect on the radiation pattern is shown in Fig. 4.

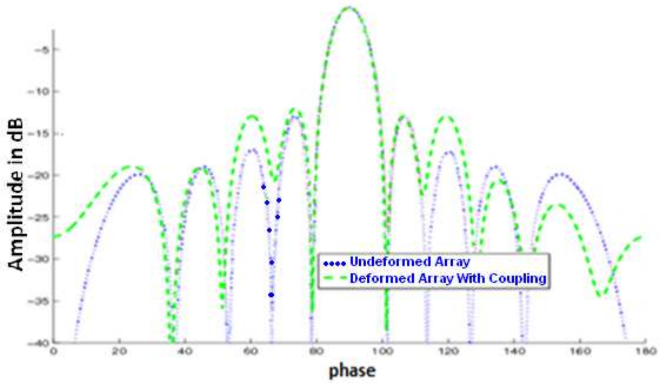

Figure 4. Vertical deformation effect on the radiation pattern.

An increase in the side lobe levels can be noticed for the deformed array radiation pattern when compared to the uniform array radiation pattern. Two correction methods are then proposed to compensate for the deformation. A direct one is based on the good knowledge of the coupling matrix hence the exact positions of the elements. The latter is based on Schelkunoff's representation which does not consider the exact positions of the elements. Instead it considers the coupling matrix which is directly related to the vertical displacement between the elements.

III. Direct Correction Method

This method can be used correctly only when the positions of the elements are exactly known in the deformed array. When this condition is satisfied, we show that a judicious modification of the voltage coefficients can be used to compensate for the displacements. The cases, with and without correction, were studied on a 10-antenna array [4]. To correct the deformed radiation pattern, we compute the excitation vector V_g for a given current vector I (usually it corresponds to the uniform array current vector) using equation (2). The result is shown in Fig. 5.

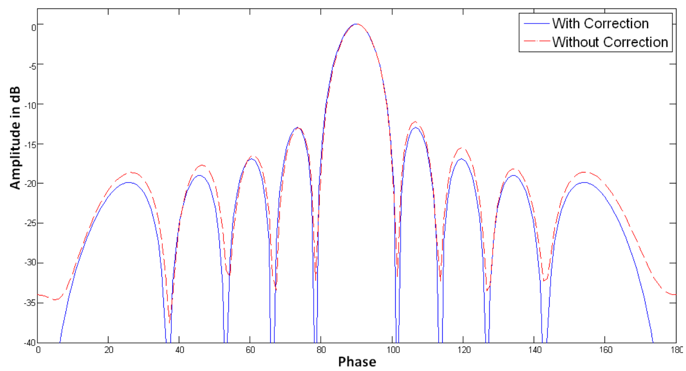

Figure 5. Radiation pattern of 10-antenna array with vertical deformation and with uniform weights, with and without correction with a $\Delta v_{max} = 0.25\lambda$.

As can be seen, the correction procedure results in a significant decrease of the side-lobe levels (SLL). When applying this correction method, the mutual coupling Z^{MU} is supposed to be perfectly known. This is not a realistic

approach as the perfect knowledge of Z^{MU} implies a perfect knowledge of the positions of the antennas.
In the next section, we propose a more robust method that is less affected by the imperfect knowledge of Z^{MU}.

IV. Correction Method Inspired From Schelkunoff's Representation

Schelkunoff's representation consists in plotting the roots of the associated polynomial on a unit circle. We remind that the associated polynomial is the ***z***-transformation of the antenna array factor.

$$F(z) = \sum_{n-1}^{N-1} i_n z^n \qquad (7)$$

Here $\boldsymbol{i_n}$ is the $\boldsymbol{n^{th}}$coefficient of the current vector I:

$$I = (Z^{MU} + Z_g^{-1})V_g \qquad (8)$$

This equation shows that when the coupling matrix $\boldsymbol{Z^{MU}}$ is altered because of erroneous values, the complex $\boldsymbol{i_n}$ coefficients are modified, modifying the associated polynomial resulting in a displacement of the roots which are represented on the unit circle in the complex plane in Fig. 6 [5]. A zero on the unit circle corresponds to a null in the antenna pattern. The placement of these zeros determines the antenna's response.
From this representation a new improved correction method is proposed. This new correction method consists in identifying the roots which represent the nulls of the radiation pattern whose positions have been significantly modified (the nulls of the ***deformed*** array) and move them back to their initial positions as for the ***uniform*** array case as it is shown in Fig. 6 where roots 1, 4, 5 and 8 have to be moved back on the unit circle.

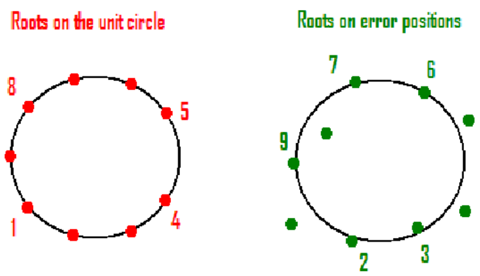

Figure 6. Example of roots displacement.

If we go deeper into technical details, Fig. 7 shows the steps taken to decide which roots have to be displaced from their erroneous positions to their initial positions.

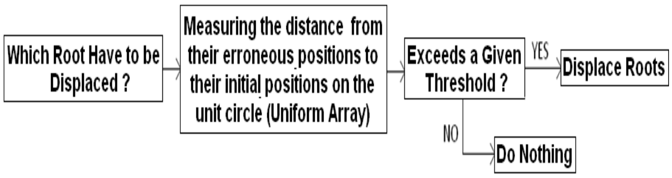

Figure 7. Roots displacement.

For instance, by not knowing the exact location of the antennas, thus the mutual impedance matrix, we define ΔZ^{MU}as a matrix of errors which can be added to Z^{MU}:

$$\tilde{Z}^{MU} = Z^{MU} + \Delta Z^{MU} \qquad (9)$$

where $\tilde{Z}^{MU}$ is the error matrix.

Each coefficient of the error matrix is a real random number. We assume a uniform distribution. The maximum error corresponds to 11% of the maximum coupling coefficient for the considered configuration when the elements are separated by λ/2 and $\Delta v_k = 0$.
This method is developed and represented in Fig. 8 by showing the roots of the polynomial for a uniform array and when the correction method is applied to the same array, vertically deformed, with an imperfect knowledge of the mutual coupling matrix. The simulation is realized for $\Delta v_{max} = 0.25\lambda$.

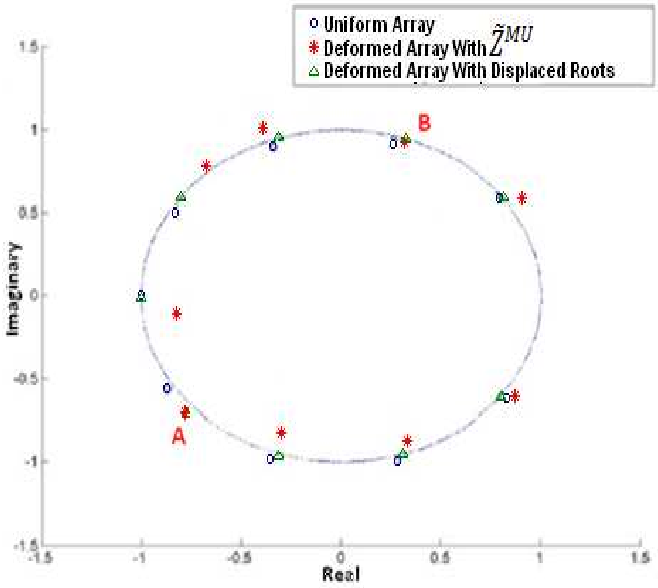

Figure 8. Representing roots positions of the associated polynomial.

The small circles placed on the unit circle represent the roots of the uniform array. The small dots represent the roots of the deformed array and finally after applying this correction method, triangles represent the displaced roots of the deformed array. We can notice that the displaced roots are so close to the uniform array roots. Two exceptions can be seen at point A and B where no root displacement is made. This is due to the measured distance from the deformed to the initial positions of the roots (uniform array), which did not exceed the threshold value. Further explanation can be interpreted by plotting the corresponding radiation patterns in Fig. 9.

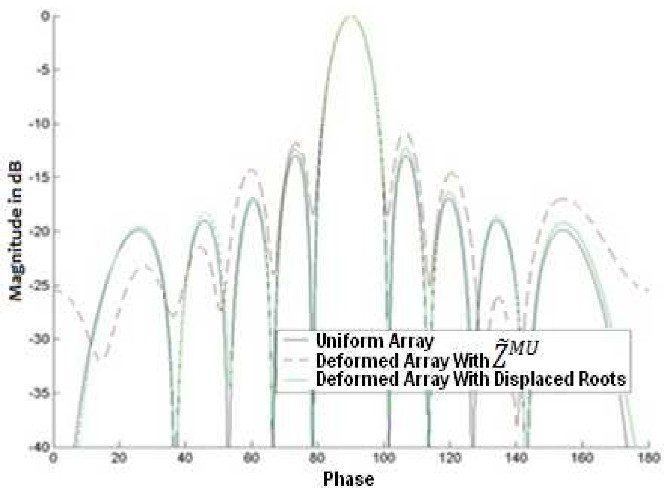

Figure 9. Radiation patterns with the new correction method.

Fig. 9 shows that large increases of Side Lobe Levels appear when the coupling matrix used for correction is imperfectly known. After applying the new correction method inspired from *Schelkunoff's* representation, an improvement of the results is noticed where the increases of SLL are limited drastically, compensating for errors in $\tilde{Z}^{MU}$. This method is adapted for different deformations, whereas it would not have been possible with the direct correction method alone.

Moreover, this new correction method inspired from *Schelkunoff's* representation has a double utility:

1) It permits to quantify the errors in $\tilde{Z}^{MU}$ to know if the correction method can be applied.

2) It permits to know the roots generating the disturbances when Z^{MU} is erroneous.

V. CONCLUSION

Two correction methods for a vertical deformation of HFSWR on buoys were introduced in this paper. The correction method inspired from Schelkunoff's representation was proved to be more robust than the direct method. Further studies will take place in the future, and theoretical interpretations will be made when significant deformations are to be applied on the array.

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