A HYBRID TECHNIQUE FOR ACCURATE MODELING OF VERY LARGE ANTENNA ARRAYS INCLUDING EDGE EFFECTS

K. F. Sabet*
EMAG Technologies Inc.
1340 Eisenhower Place, Ann Arbor
MI 48108, USA
ksabet@emagtechnologies.com

Kin Y. Sze
EMAG Technologies Inc.
1340 Eisenhower Place, Ann Arbor
MI 48108, USA
kinsze@emagtechnologies.com

Donghoon Chun
EMAG Technologies Inc.
1340 Eisenhower Place, Ann Arbor
MI 48108, USA
donghoon@emagtechnologies.com

***Abstract* –** This paper presents an efficient technique for the modeling of large-scale antenna array structures. The proposed hybrid technique combines the full-wave analysis of a periodic array of infinite extent with the full-wave analysis of edge elements of the array to capture the edge effects. The method of moments (MoM) is used as the full-wave simulation method. Numerical results are presented for some large antenna arrays. [1]

TABLE OF CONTENTS

1. INTRODUCTION

The full-wave analysis of large-scale phased array systems poses a very challenging computational electromagnetic problem. Conventional full-wave techniques such as the Method of Moments (MoM) can handle small- to medium-scale problems relatively easily. When the size of the array exceeds a hundred elements, full-wave techniques reach their limit of applicability. For larger arrays, periodic simulators are often utilized, whereby the array is assumed to have an infinite extent. However, periodic techniques cannot predict the edge effects due to the radiating elements located at the boundary of the finite-size array structure. Therefore, it is essential to develop a technique that utilizes the full-wave analysis of the array in an efficient manner while being able to recognize the finite size of the array and account for the edge effects.

This paper provides a brief overview of a previously proposed technique, called the **Decompose-Solve-Recompose** **(**DSR**)** scheme [1], that is adapted

---

[1] 0-7803-7651-X/03/$17.00

to the modeling of planar Large Phased Array (LPA) systems. The resulting 2D spatial DSR technique, known as the Hybrid Edge-Periodic DSR technique, requires the decomposition of a large planar array into an outer edge "ring" array and a central periodic array block. In addition, its computation speed and efficiency may be further enhanced by means of a 2D PNM algorithm described in [1].

2. THE DSR TECHNIQUE

A 2D spatial DSR analysis, using a Hybrid Edge-Periodic DSR technique, is employed for the modeling of a planar array of dipoles as depicted schematically in Fig. 1. This DSR technique is new and involves the decomposition of an LPA into an outer edge "ring" array and a central periodic array block, as shown in the figure. Each of these decomposed arrays are solved independently using the full-wave MoM (or any other full-wave analysis methods), and subsequently, recomposed back as a solution to the original problem.

Additional improvements of the Hybrid Edge-Periodic DSR technique may be achieved through the use of region "overlapping" between the edge rings and the periodic array block, as implemented similarly in the PNM algorithm in [1]. An optimal choice of edge element ring width can also yield better accuracy. The mechanism of region "overlapping" requires that inner edge rings be discarded and outer rings retained during the recomposition of the solution.

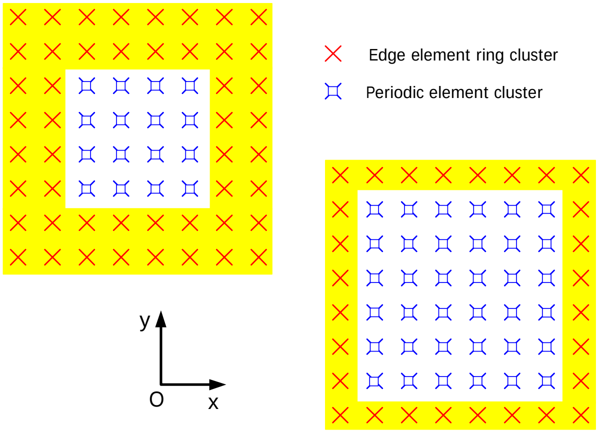


Fig. 1: Discarding an edge element ring for an 8x8 planar array using the Hybrid Edge-Periodic DSR technique. The original edge element ring cluster (top left) is 2 rings wide, and with the second ring in the cluster discarded (i.e. overlapped by the periodic element cluster), only the first ring is retained (bottom right).

Periodic elements are then substituted in their place so that the final solution will still represent the correct number of array elements and their spatial positions in Euclidean space, as illustrated in Fig. 1. That is, Total Rings = Rings Retained + Rings Discarded. The discarded rings actually serve as "pawns" for approximating the mutual coupling effects on the rings retained. Nevertheless, the discarding of edge element rings is generally more expensive since more rings are necessary and the computation cost increases with increasing the number of total rings (due to the use of full-wave numerical methods for the edge array).

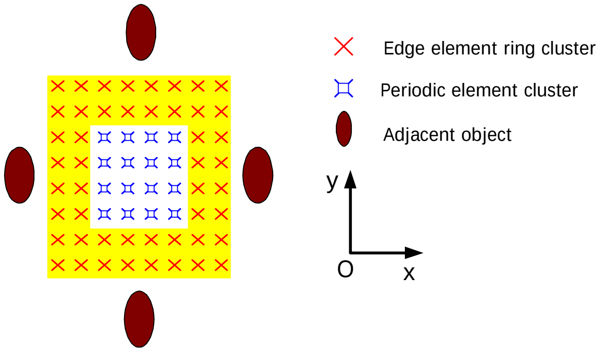


Fig. 2: Schematic of a Hybrid Edge-Periodic DSR model for the analysis of an LPA in the vicinity of other objects.

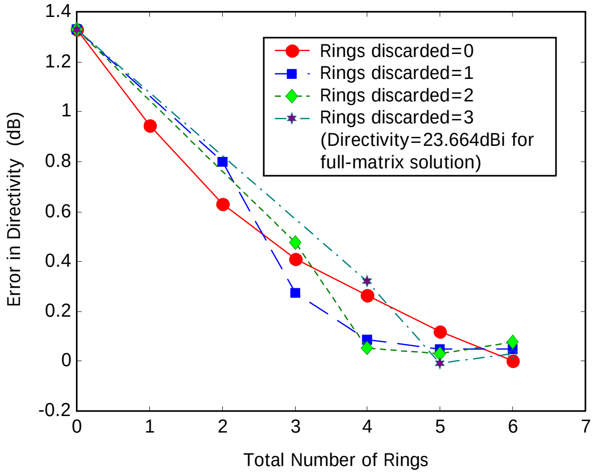


Fig. 3: Hybrid Edge-Periodic DSR cost function curves for a uniformly-excited 12x12-element array of uniform microstrip dipoles etched on a $\varepsilon_r=2.2$ substrate of thickness $0.188\lambda_d$: error in directivity.

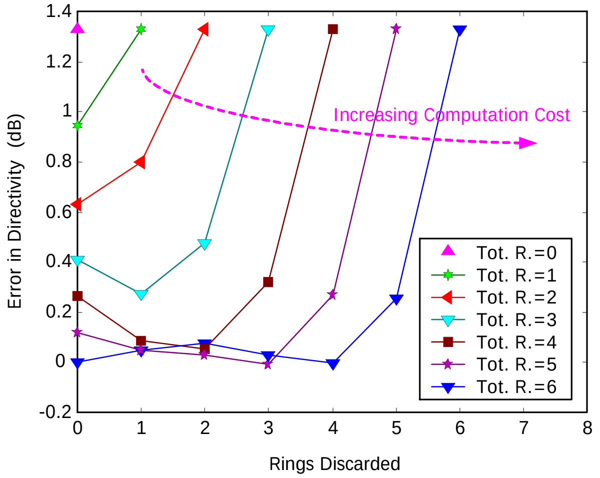


Fig. 4: Hybrid Edge-Periodic DSR cost function curves for a uniformly-excited 12x12-element array of uniform microstrip dipoles etched on a ε_r*=2.2 substrate of thickness 0.188*λ_d*: effect of overlapping regions (where Tot. R. ≡Total Rings). Oriented parallel to the x-axis, the dipoles have lengths and widths 0.578*λ_d *and 0.003*λ_d*, respectively, and element spacings in the x- and y- directions are 0.742*λ_d *and 0.494*λ_d*, respectively.*

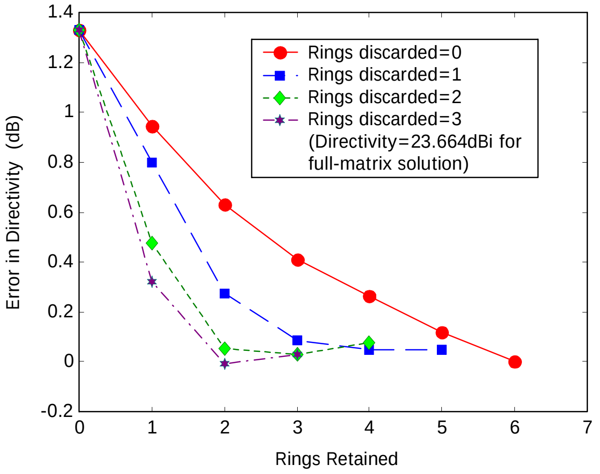


Fig. 5: Directivity convergence due to edge element rings for the 12x12-element dipole array represented in Fig. 3.

For the modeling of an LPA on a platform in the vicinity of objects such as screws, fasteners and pins, as schematically depicted in Fig. 2, the Hybrid Edge-Periodic DSR technique will be employed with additional considerations for adjacent objects to be solved as part of the edge element array in the DSR algorithm. For the ease of developing the DSR technique, however, uniform LPAs are utilized as simple test examples the proof of concept, since their radiation behavior is generally well understood. Simulation results for non-uniform LPAs will be addressed during presentation.

3. FAR-FIELD RADIATION CHARACTERISTICS

The improvements of the spatial DSR technique over the traditional periodic array windowing approach is observed for a 12x12-element uniform array of microstrip dipoles etched on a ε_r=2.2 substrate of thickness 0.188λ_d, where $\lambda_d = \lambda_o/\sqrt{\varepsilon_r}$. The array dipoles are center-fed, each having a length and width of 0.578λ_d and 0.003λ_d, respectively, and their center-to-center element spacings in the x- and y- directions are 0.742λ_d and 0.494λ_d, respectively. These dipoles are oriented parallel to the x-axis, giving an E_x field polarization

For the 12x12-element array, directivities are computed using the full-matrix (exact solution), periodic array windowing and Hybrid Edge-Periodic techniques. Since computation cost is a very important criterion in the analysis and design of an LPA, the Hybrid Edge-Periodic DSR cost functions for this LPA are analyzed and presented in Fig. 3. In the figure, the error in directivity is given by D_o- D_o^{fm}, where D_o is the directivity of the LPA computed using the Hybrid Edge-Periodic DSR, and D_o^{fm} is that computed using the full-matrix MoM. The amount of region overlap is implicitly represented by the number of rings discarded. For the 12x12-element array, the full-matrix solution is equivalent to the case of having a total of 6 rings with no rings discarded (i.e. with no periodic element utilized in the DSR modeling), while the periodic array windowing solution is equivalent to that without any rings (i.e. with only periodic elements utilized in the DSR simulation). For example, a zero number of rings corresponds to a windowed periodic array solution, which yields a 1.329dB error in directivity. For a total number of rings between these two extremes, results obtained are from combinations of solutions for both edge rings and inner periodic elements.

Since the edge element rings are solved using the full-wave MoM, computation cost increases with increasing number of total rings, and also with increasing number of rings discarded. Nevertheless, optimal conditions for best accuracy at minimal cost can be obtained from data in Fig. 4. The directivity convergence for the 12x12-element array is depicted in

Fig. 5, with the full-matrix solution represented by the data point for 6 retained rings, and the periodic array windowing, by points for no retained rings. Also, the rate of convergence improves with larger number of rings discarded.

Far-field radiation patterns for the 12x12-element array are also computed using the full-matrix (exact solution), periodic array windowing and Hybrid Edge-Periodic techniques, and are illustrated in Fig. 6. For the Hybrid Edge-Periodic DSR modeling, radiation patterns are obtained using an optimal total of 5 edge element rings, which yields the best results for the 12x12-element array. The effect of region overlap on radiation patterns is negligible for this case, except for a slight improvement in the directivity (< 0.05dB) using a single discarded ring. Nonetheless, this spatial DSR technique is capable of accurately predicting null levels and side-lobe levels (SLL), as opposed to the periodic array windowing method. In essence, pattern improvements are generally attributed to the choice of optimal total number of rings. As a further investigation, the 12x12-element array is expanded to a 24x24-element array with same array parameters. Radiation patterns for this new LPA will be discussed during presentation.

4. CONCLUSION

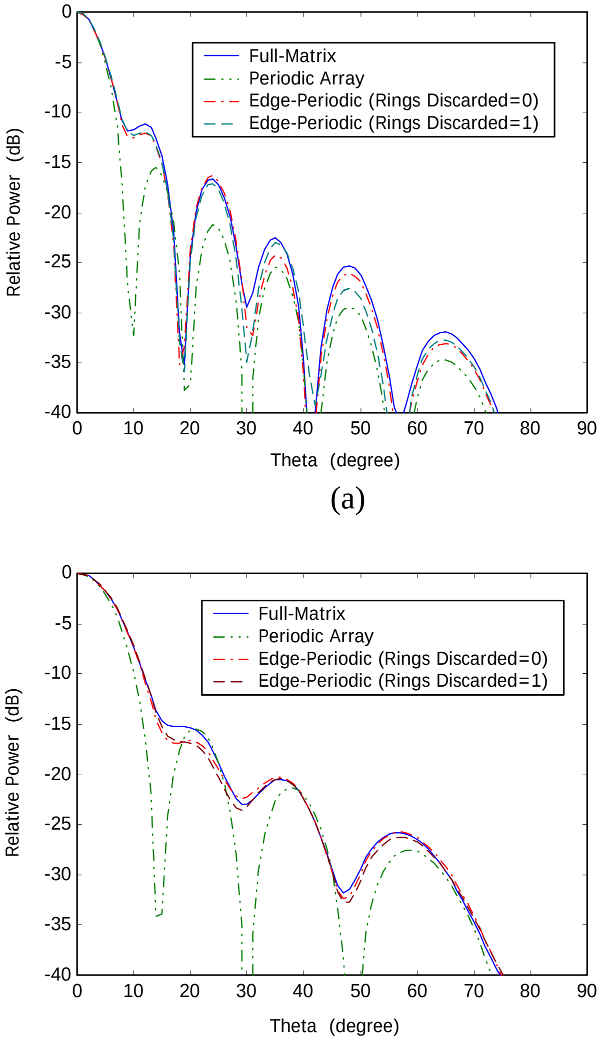
A region overlap mechanism, similar to that utilized in PNM, is implemented into a newly proposed Hybrid Edge-Periodic DSR technique for the 2D spatial DSR analysis of planar LPA systems. With an appropriate choice of edge element rings retained and discarded, the modeling of a medium-scale LPA provides very good accuracy. For a large-scale LPA, this modeling using region overlap also improves simulation results. However, the periodic array windowing approach yields acceptable accuracy for a uniform LPA, while the spatial DSR method may prove to be more superior and may be the only practical solution for a large-scale non-uniform LPA (non-uniform LPA results will be discussed during presentation).

ACKNOWLEDGEMENT

This research work was supported in part by the Office of Naval Research under the Contract No. N00178-02-C-3001.

REFERENCES

[1] Qiubo Ye; "Electromagnetic scattering by numerical methods applicable for large structures"; Ph. D. Thesis; University of Manitoba, Winnipeg, Manitoba; July 2000.



(a)

(b)

Fig. 6: Far-field radiation patterns of a uniformly-excited 12x12-element array of uniform microstrip dipoles etched on a ε_r=2.2 substrate of thickness 0.188λ_d: (a) E-plane, and (b) H-plane. Oriented parallel to the x-axis, the dipoles have lengths and widths 0.578λ_d and 0.003λ_d, respectively, and element spacings in the x- and y- directions are 0.742λ_d and 0.494λ_d, respectively. The Hybrid Edge-Periodic results are computed using a total of 5 edge element rings.