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A Hybrid MoM-Asymptotic and Circuit Based Analysis of Large Finite Patch Antenna Arrays with a Printed Feed Network

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1 Introduction

An analysis of electromagnetic (EM) radiation and coupling associated with large multiple finite periodic microstrip patch antenna arrays on a grounded slab together with their feed networks is developed. Typical patch array and feed network combinations are shown in figure 1. In general, the more the number of elements in an antenna array, the larger the size of corresponding feed network and the more computational resources required for solving this problem using full-wave or MoM analysis. Furthermore, feed networks are designed so that the antenna arrays achieve their desired performance. In most cases this design process may require many iterations, which can result in a highly inefficient and time-comsuming process and can rapidly become intractable for large antenna arrays. To significantly improve the efficiency of the analysis of such problems, an approximate hybrid method is developed here, which partitions the problem so that one part treats the antenna arrays alone, and the other treats the feed networks alone. These two parts are then systematically combined via the generalized Thevenin's theorem. The approximation in this hybrid approach, which provides a rapid initial design, results from the circuit solver that does not provide any contribution to the radiation or scattering by the feed lines. This is reasonable since feed lines are designed so that their radiation is negligible.

2 Summary of the Method

The approach developed in this paper is based on partitioning, which consists of the following key steps:

1. Full wave-asymptotic MoM solver for analyzing antenna array elements only
2. Circuit solver for designing only the feed networks
3. Combining the two parts above via a generalized multiport Thevenin's theorem

Step 1: Full wave-Asymptotic solver for Antenna Array Analysis

A hybrid numerical full wave-asymptotic solution is developed to analyze the antenna array elements. It is based on the method of moments (MoM) solution of the integral equation governing the unknown antenna element currents. Numerous modifications have been introduced to significantly improve the efficiency of the MoM solutions, such as the use of Discrete Fourier Transform (DFT) basis set to represent the array current distributions[1] together with an iterative solver (e.g.,[2]), the hybrid combination of numerical and asymptotic high frequency approach for calculating the MoM matrix elements fast, etc. Here, the evaluation of the Green's function for the grounded substrate of infinite extent is significantly speeded up, since the conventional slowly convergent Sommerfeld integral form of the Green's function is replaced by its asymptotic high frequency closed form [3]. This approach provides a great improvement since it can significantly reduce the time required for filling the MoM operator matrix. More importantly, the DFT with acceleration allows one to solve a 10^6 element array in less than one hour on a desktop personal computer.

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Step 2: Feed Network Simulation

One can employ a full wave analysis for both the antenna arrays and the feed networks as in the work of [4]. However, including feed lines in the full wave solver would significantly increase the number of unknowns and thus significantly increase the computational complexity. Thus, a simplification of the problem is introduced here by assuming that the radiation from the feed network is negligible and the feed network is treated purely from the non-radiating circuit point of view. The feed network can then be designed and analyzed using the commercially available Advanced Design System (ADS) software package or some other similar software. Generally the circuit analysis is much faster than the full wave analysis, hence, it is more suitable for the design of feed networks which may require a certain number of iterations. Furthermore, there are optimization tools in most circuit solvers which can help to better design the feed networks.

Step 3: Hybrid Combination of Full Wave Array Analysis and Feed Circuit Analysis

Figure 3 illustrates the schematics of the two separate parts of the problem described in the previous steps, namely the antenna array elements and the feed network. A generalized multiport Thevenin's theorem is next utilized to systematically couple these two separate parts.

Let $[Z_{oc}]$ be the open circuit impedance matrix of the feed network, which can be found using a circuit design tool as mentioned above. Also, let $[Z_L]$ be the load impedance matrix given by:

$$[\mathbf{Z}_L] = \begin{bmatrix} (Y_g + Y_L)^{-1} & 0 \cdots 0 \\ 0 & \\ \vdots & [\mathbf{Z}_p] \\ 0 & \end{bmatrix}, \tag{1}$$

in which $[\mathbf{Z}_p]$ represents the port impedances of the antenna array. It is noted that the array port impedances are obtained by the full wave MoM solver. The generalized Thevenin's theorem [5] yields:

$$[\mathbf{V}_g] = ([\mathbf{Z}_{oc}] + [\mathbf{Z}_L])[\mathbf{I}], \tag{2}$$

where $[\mathbf{V}_g]$ and $[\mathbf{I}]$ represent the source voltage vector and the port current vector, respectively. For the radiation problem, a voltage source (or equivalently current source) is used to feed the antenna array, while in the receiving problem, the open circuit voltages received by the array will act like voltage sources to the feed network. Thus, in the radiation problem, $[\mathbf{V}_g] = [V_g, 0, \cdots, 0]^T$,where V_g is the voltage source, while in the receiving problem, $[\mathbf{V}_g] = [0, V_1, V_2, \cdots, V_n]^T$, where V_i is the open circuit voltage received at port i of the network. Using (2), one can solve for the current vector, which can be used to compute the radiation pattern and received power.

For an array with a large number of array elements, using only one corporate feed network for the whole array may become inefficient and lead to difficulties in design due to the increasing propagation length and reflections at the network junctions. Consequently, to improve the performance, it is generally preferable to build an array by combining several subarrays with a separate feed network for each subarray thereby leading to a better design and an improved performance. In addition, if one can arrange an array such that it consists of several identical subarrays, then the same feed network geometry can be used for all subarrays. For the case of the subarray configuration, the approach described in the previous section can be used by appropriately modifying $[\mathbf{V}_g]$, $[\mathbf{Z}_{oc}]$, and $[\mathbf{Z}_L]$ to represent those of such a configuration.

3 Numerical Results and Conclusion

In this study, the coupling between two identical transmitting and receiving patch antenna arrays is computed as follows:

1. Find the current at each antenna element port of the transmitting array
2. Use currents in 1 as the excitation and solve for the radiated field
3. Use the radiated field from the transmitting array as the incident field for the receiving array and solve for the open circuit voltage at each receiving antenna element port
4. Calculate the current at each receiving subarray port from the element open circuit voltages in 3

Figure 1 shows the 8×8 patch antenna array used in numerical results. It consists of four 4×4 subarrays and the numbers 1, 2, 3 and 4 in the figure indicate the index of the subarrays. Also, the following parameters are used in numerical results:

Patch Dimension:	0.85×0.65	Element Spacing:	1.75 cm
Substrate Thickness:	1.59 mm	Substrate Dielectric Constant:	2.32
Operating Frequency:	12.8 GHz	Scan Angle	$\theta = 10^\circ, \phi = 0^\circ$

The radiation pattern of this array is shown in figure 2, and figure 4 shows the received current at each subarray port as a function of separation between two arrays when two such identical arrays are laterally separated. Also, figure 5 shows the result when two arrays are vertically separated. By comparing the two results, it can be seen that the coupling is much stronger when two arrays are laterally separated as can be predicted since the patch current flow along this direction of separation. The method developed here is seen to be relatively efficient and can easily be extended to solve problems with much larger arrays. Future study will include the comparison with reference full wave analysis results for the entire feed network along with array elements in order to verify the effectiveness of the method.

References

[1] P. Janpugdee, P. H. Pathak, and P. Mahachoklertwattana, "A fast hybrid dft-mom for the analysis of large finite periodic antenna arrays in grounded layered media," in *IEEE USNC/URSI National Radio Science Meeting*, (Columbus, OH), June 2003.

[2] T. J. Peters and J. L. Volakis, "Application of a conjugate gradient fft method to scattering from thin material plates," *IEEE Trans. Antennas Propagat.*, vol. 36, pp. 518–526, April 1988.

[3] C. W. Chuang, P. Janpugdee, and P. H. Pathak, "Efficient asymptotic closed form evaluation of the mom impedance matrix for antennas and large antenna arrays in a grounded multilayered medium," in *IEEE USNC/URSI National Radio Science Meeting*, (Columbus, OH), June 2003.

[4] G. X. Fan and J. M. Jin, "Scattering from a cylindrically conformal slotted waveguide array antenna," *IEEE Trans. Antennas Propagat.*, vol. 45, pp. 1150–1159, July 1997.

[5] J. Mautz and R. Harrington, "Modal analysis of loaded n-port scatterers," *IEEE Trans. Antennas Propagat.*, vol. 21, pp. 188–199, March 1973.

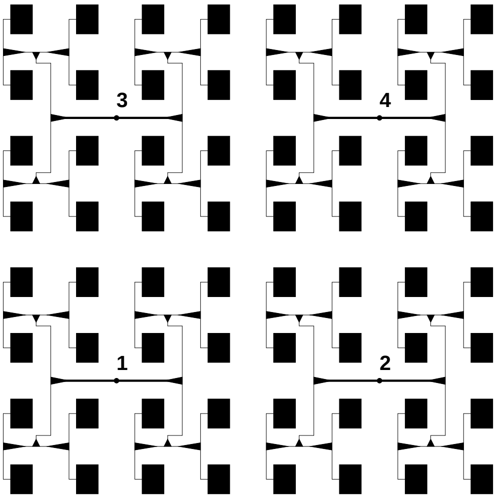

Figure 1: 8×8 element patch antenna array consisting of 4 subarrays

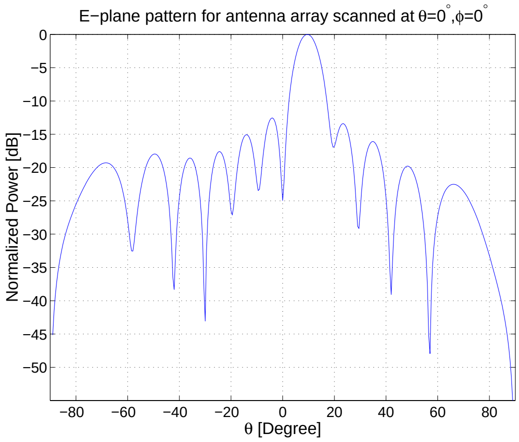

Figure 2: Radiation E-plane pattern of an 8×8 array scanned at $\theta = 10°, \phi = 0°$

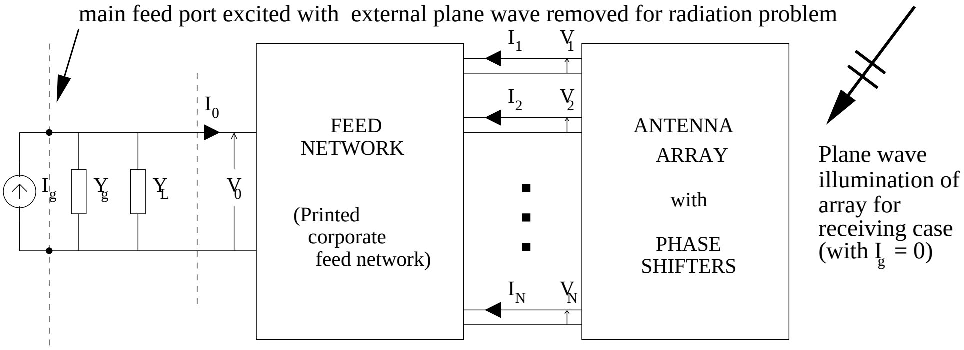

Figure 3: An array-feed network configuration. Source current I_g and admittance Y_g are assumed known. Also load admittance Y_L is assumed known.

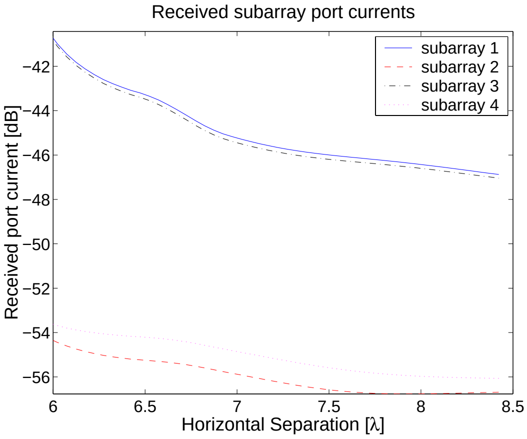

Figure 4: The received subarray port currents when two arrays are laterally separated

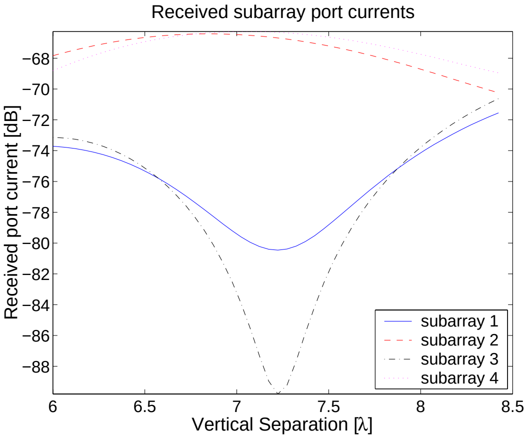

Figure 5: The received subarray port currents when two arrays are vertically separated