Analysis of a Large Scale Low-Profile Narrow-Wall Slotted Waveguide Array by Parallel MoM Using Higher Order Basis Functions under MPI Circumstance

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1. Introduction

Low profile high gain antenna array can be realized easily using narrow-wall slotted waveguide, which are widely used in modern radar and communication systems. Recent years, the design and analysis of narrow-wall slotted waveguide array is much more emphasized. As part of each slot is cut into the broad-wall, it is difficult to represent it using equivalent magnetic currents as in the conventional method-of-moments (MoM) approach [1]. Also, there exists no suitable Green's function for this kind of geometry if the conventional MoM is employed [2].Recently, the radiation patterns of narrow-wall inclined slots have been computed using the MoM based on the electric field integral equation (EFIE) by Li et al [1] [2]. As the mutual couplings among the slots are taken into account, the method is more accurate than the conventional asymptotic methods [2]. However, the MoM based on the Rao-Wilton-Glisson basis functions (RWGs) produces a very large number of unknowns for electrically large structures [3]. To reduce the number of unknowns, higher order polynomials over wires and quadrilateral plates are used as basis functions over larger subdomain patches [2][4]. The use of higher order basis functions significantly reduces the number of unknowns. To further reduce the total wall clock time, the large dense MoM matrix is divided into a number of smaller block matrices that are nearly equal in size and distributed among all the available process in the parallel method.

2. Basic Theory

2.1. Higher Order Basis Functions

Flexible geometric modeling can be achieved by using truncated cones for wires and bilinear patches to characterize other surfaces [4]. Both the inner and the outer part of each waveguide are discretized into bilinear surfaces. The feed pin is modeled by truncated cones.

The polynomials approximation for the current distributions over the cone can be written as

$$I(s) = I_1 N(s) + I_2 N(-s) + \sum_{i=2}^{N_s} a_i \, S_i(s), \quad -1 \le s \le 1 \tag{1}$$

$$N(s) = \frac{1-s}{2} \quad , \quad S_i(s) = \begin{cases} s^i - 1, & i \ \ is \ \ even \\ s^i - s, & i \ \ is \ \ odd \end{cases} \tag{2}$$

Current distribution over a bilinear surface is decomposed into its p and s components. For a general case, we consider the s components. Its approximation can be expressed as

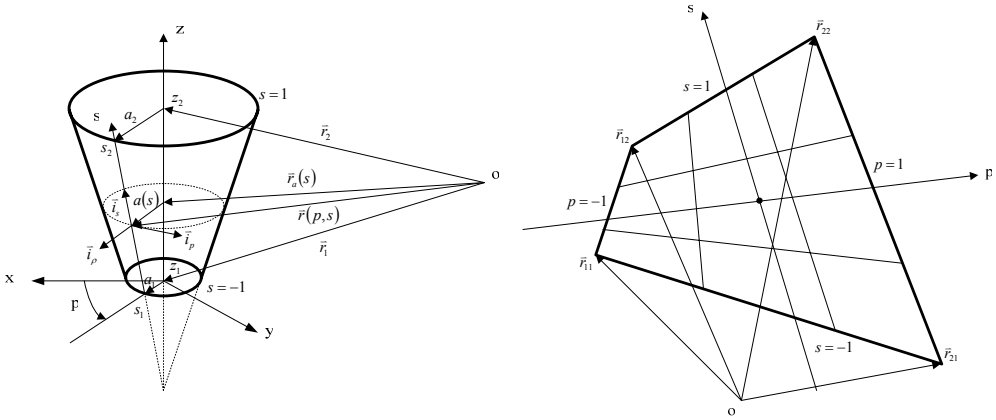
$$\vec{J}_s(p,s)=\sum_{i=0}^{N_p}\left\{c_{i1}\vec{E}_{i1}(p,s)+c_{i2}\vec{E}_{i2}(p,s)+\sum_{j=2}^{N_s}a_{ij}\vec{P}_{ij}(p,s)\right\} \tag{3}$$

$$c_{i1}=\sum_{j=0}^{N_s}a_{ij}(-1)^j,\quad c_{i2}=\sum_{j=0}^{N_s}a_{ij} \tag{4}$$

$$\vec{E}_{ik}(p,s)=\frac{\vec{\alpha}_s}{\left|\vec{\alpha}_p\times\vec{\alpha}_s\right|}\begin{cases}p^iN(s), & k=1\\ p^iN(-s), & k=2\end{cases} \tag{5}$$

$$\vec{P}_{ij}(p,s)=\frac{\vec{\alpha}_s}{\left|\vec{\alpha}_p\times\vec{\alpha}_s\right|}p^iS_j(s) \tag{6}$$

$$\vec{\alpha}_p=\frac{\partial\vec{r}(p,s)}{\partial p}\quad,\quad\vec{\alpha}_s=\frac{\partial\vec{r}(p,s)}{\partial s} \tag{7}$$



(a) (b)

Figure 1: Geometric model: (a) A right-truncated cone defined by position vectors and radii of its beginning and end; (b) A bilinear surface defined by four vertices.

	0		1		2		0		1
0	11	12	13	14	15	16	17	18	19
	21	22	23	24	25	26	27	28	29
1	31	32	33	34	35	36	37	38	39
	41	42	43	44	45	46	47	48	49
2	51	52	53	54	55	56	57	58	59
	61	62	63	64	65	66	67	68	69
0	71	72	73	74	75	76	77	78	79
	81	82	83	84	85	86	87	88	89
1	91	92	93	94	95	96	97	98	99

(a)

	0				1			2	
0	11	12	17	18	13	14	19	15	16
	21	22	27	28	23	24	29	25	26
	71	72	77	78	73	74	79	75	76
	81	82	87	88	83	84	89	85	86
1	31	32	37	38	33	34	39	35	36
	41	42	47	48	43	44	49	45	46
	91	92	97	98	93	94	99	95	96
2	51	52	57	58	53	54	59	55	56
	61	62	67	68	63	64	69	65	66

(b)

Figure 2: Two dimensional matrix distribution using ScaLAPACK: (a) a 9×9 matrix divided into 2×2-sized blocks; (b) the rearrangement of the blocks in (a) for a 3×3 process grid.

2.2. The Matrix Partition Scheme

Assume that the matrix A is a large dense matrix, it can be divided into smaller blocks and distributed to each process grid using ScaLAPACK, as illustrated in Fig. 2.

Finally, the solution of the matrix equation is executed by the parallel LU decomposition solver based on the ScaLAPACK library package.

3. Numerical Results and Discussions

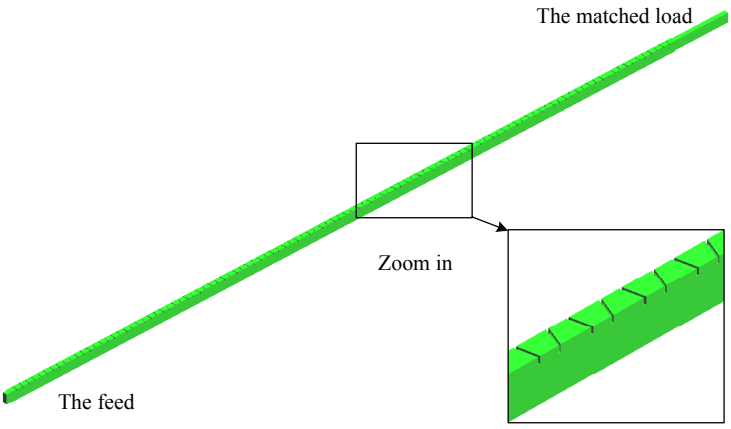


Figure 3: The model of a side-slotted waveguide array with 108 slots

To validate the accuracy and efficiency of this method, the computational result for a traveling waveguide array with 108 narrow-wall slots is first presented. The waveguide is chosen as the WR-90 waveguide (X-band), and a wall thickness of 1.0 mm is assumed. The center frequency of the array is 9.375 GHz. The distance between the two adjacent slots is 15.5mm. A -30 dB Taylor distribution is used in the array design. The radiation pattern is shown in Fig. 4.

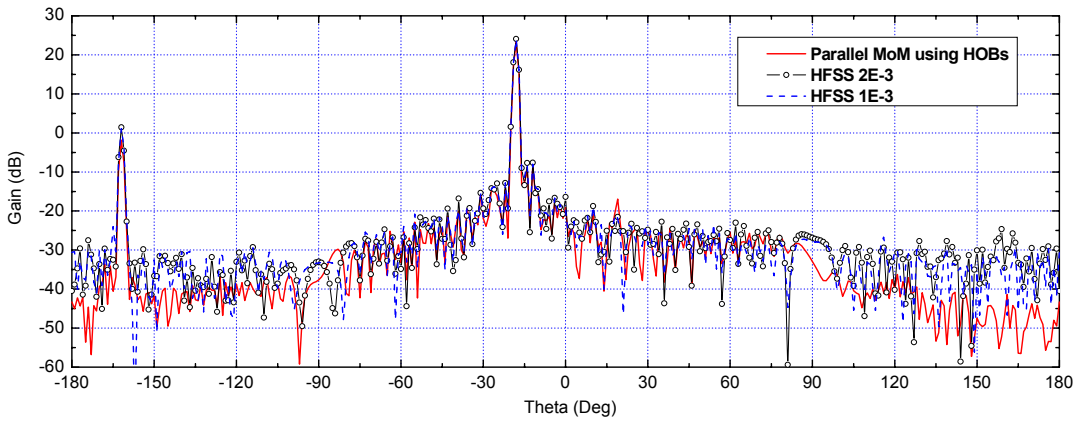


Figure 4: Comparison of the radiation pattern from Parallel MoM using HOBs and HFSS

Table 1: The comparison of RAM and CPU time for 108 slots

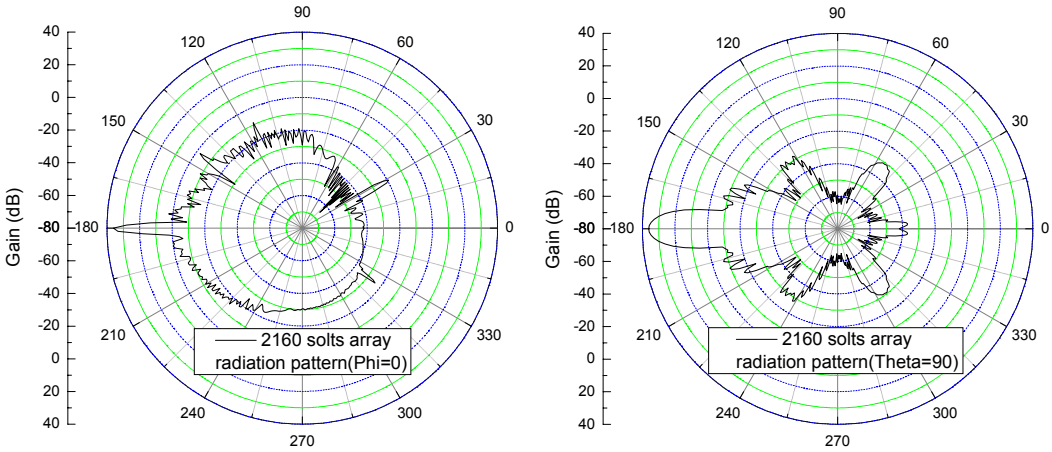
algorithm/software	Number of Cores	Meshed Elements	Memory (GB)	Time (sec)
Parallel MoM using HOBs	192	5771	13.2	441
Parallel HFSS (convergence 2E–3)	192	253562	18.0	5921
Parallel HFSS (convergence 1E–3)	192	1139447	48.8	16200

From comparison in Fig. 4, it can be seen that the computed result by the Parallel Higher Order MoM agrees well with the HFSS result in the mainlobe region.

From Table 1, it is clearly seen that this method requires not only less memory than HFSS, but also its computation time can be as low as 2.7% for the same accuracy of the result.

Then, twenty 108-slot waveguides are utilized to form a large array, 2160 slots in total. The distance between two adjacent waveguides is 20.0mm. A -40 dB Taylor distribution is used in the feedings.

The E-plane and H-plane radiation patterns of the 2160-slot waveguide array are given in Fig. 5.



(a) (b)

Figure 5: Radiation patterns of the 2160-slot waveguide array: (a) E-plane; (b) H-plane.

From Fig. 5, it can be seen that the computed results by parallel MoM using HOBs agrees well with the designed expectations.

4. Conclusion

The large scale waveguide array can be easily analyzed by parallel MoM using the higher order basis functions. The number of unknowns and the memory requirement is reduced significantly. A load balanced parallel method is achieved by a matrix partition scheme, so the total wall clock time for solving a large dense matrix is shortened. Its accuracy, efficiency and applicability are also validated through some numerical examples. It is instructive to the further researches on solving electrically large scale problems.

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