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Implementation of Electromagnetic Scattering From Conductors Containing Loaded Slots on the Connection Machine CM-2

by

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Abstract

The problem of electromagnetic scattering from a plane conductor containing multiple apertures is studied. The two slots are terminated or interconnected by a microwave network internal to the plane through two waveguides. The problem is formulated as an operator equation. A matrix method of solution is outlined using the method of moments that was first developed to simulate EM fields by the third author[1]. The problem is interpreted using generalized network parameters. In this paper, a massively parallel architecture is used. Two versions of the algorithm on the Connection Machine are developed. The first version is machine independent and is written in standard Fortran 90. Better performance was obtained by the second version which is built around the efficient use of the CM scientific Subroutine Library(CMSSL). We show that opportunities for parallel computations are abundant in the Method of Moments. Our results showed that rejuvenating a sequential code to take the advantages of massively parallel machines is worthwhile. The computation of this parallel code runs on 16K CM-2 4000 times faster than the sequential code that runs on a SPARC IPC station.

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1. Introduction

The coupling of electromagnetic fields between two regions isolated except for one or more aperture is a widely encountered problem in electromagnetics. Electromagnetic compatibility, electrostatic discharge, electromagnetic pulse, screening technics in computer, microwave, integrated circuit design, electromagnetic biology, and too many other applications are of considerable interest. The exact knowledge of their characteristics is essential. The most general case is scattering by conducting bodies containing loaded apertures. By loaded apertures we mean apertures which are terminated or interconnected by a microwave network internal to the body. A general procedure for formulating problems involving electromagnetic coupling through apertures in conducting bodies was surveyed by Harrington [1]. The loaded aperture cases can be formulated in the same way. By using the method of moments[2,10], the formulations can be interpreted into a generalized network formulation.

Several computer programs have been developed to compute the electric current induced on a conducting body of revolution excited by an incident plane wave[3,4 ,5].In the research area of computable electromagnetics, to get a numerical solution with an acceptable error on traditional computers is usually a very time consuming task. Massively parallel machines offer a very attractive approach for such implementations. On the other hand one has to spend considerable time on analyzing the algorithm and converting Fortran 77 codes to Fortran 90 codes before running on such machines.

This application is being adopted as a language benchmarking tool. It will be included in the Fortran D and High Performance Fortran benchmarking test suite under development at NPAC by the second auther and other collaborators.

2. The EM Scattering Imitation Model

Fig.1 shows the structure, in which a plane wave is incident on a conducting plane containing two slots terminated by a microwave network. In region 'A', a plane wave is incident on a conducting plane containing two slots. The width of one slot is a, and the other one is b. The distance between apertures is 2d. In region 'B', two parallel plate waveguides are connected by a microwave network [Y].

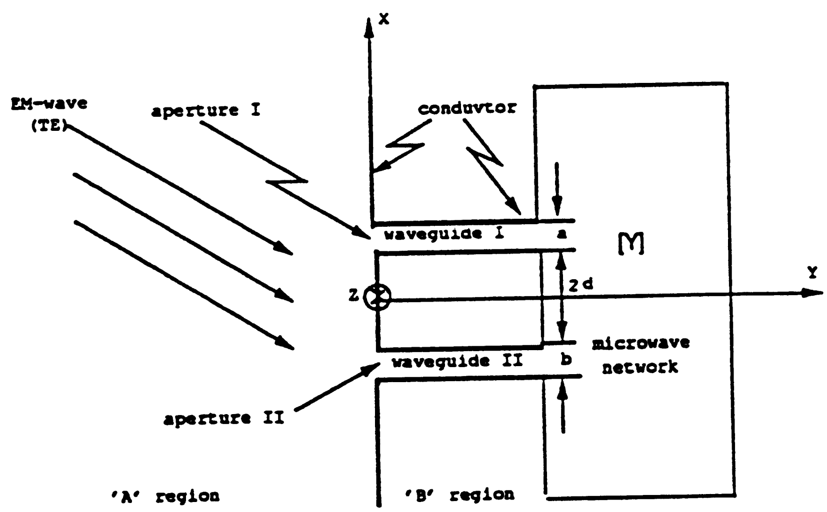


Figure 1: The original problem

The lengths of waveguides are l_1 and l_2, respectively.

By using the equivalence principle[2,9], the original problem can be divided into two equivalent parts, as shown in Fig.2.

In region 'A', the excitation is transverse electric (TE) to z (the slot axis). The excitation is specified by H_z^{sc}, assumed known.

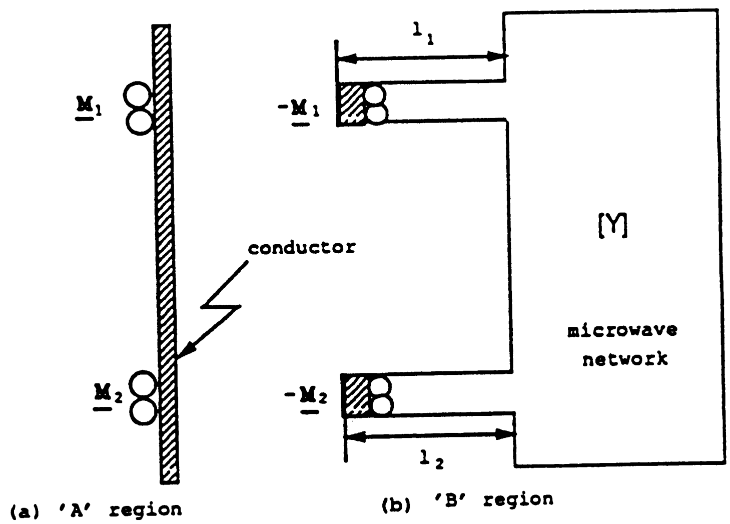


Figure 2: The Equivalent problems

The total field is equal to the incident wave plus the field produced by the equivalent magnetic currents $\underline{M}_1$ and $\underline{M}_2$ with the apertures covered by an electric conductor[4,11,13].

$$\underline{M}_j = \underline{E}_j \times \underline{n} \qquad (j = 1, 2) \tag{1}$$

The magnetic current sheets $\underline{M}_j$ are placed on the aperture areas just external to the closed plane conductor. In (1), $\underline{E}_j$ are the electric fields in the apertures 1 and 2, respectively, and n is the outward directed normal, here $\underline{n}$ is the unit vector in y direction. Since $\underline{E} \times \underline{n} = 0$ over the body except in the apertures, M exists only over the aperture areas, as shown in Fig.2(a).

In region 'B', the magnetic current sheets $-\underline{M}_1$ and $-\underline{M}_2$ are placed just internal to the closed aperture areas with electric conductor. This is shown in Fig.2(b), where $\underline{M}_1$ and $\underline{M}_2$are given by (1).

We now use $\underline{H}^a(\underline{M}_1)$ and $\underline{H}^a(\underline{M}_2)$ to denote the electromagnetic field in region 'A' due to the magnetic current $\underline{M}_1$ and $\underline{M}_2$, respectively, with the apertures shorted.

Hence, the total field in region 'A' is given by,

$$\underline{H}_t^a = \underline{H}_t^{sc} + \underline{H}_t^a(\underline{M}_1) + \underline{H}_t^a(\underline{M}_2) = \underline{H}_t^{sc} + \sum_{i=1}^{2} \underline{H}_t^a(\underline{M}_i) \tag{2}$$

The total field in region 'B' is

$$\underline{H}_t^b = \underline{H}_t^b(-\underline{M}_1) + \underline{H}_t^b(-\underline{M}_2) = -\sum_{i=1}^{2} \underline{H}_t^b(\underline{M}_i) \tag{3}$$

Since the boundary condition is satisfied across the aperture regions, we equate the tangential components of $\underline{H}$ over the aperture regions(A_i), that is, $\underline{H}_t^a = \underline{H}_t^b$. Then (2) and (3) reduce to

$$-\sum_j \underline{H}_t^{ai}(\underline{M}_j) - \sum_j \underline{H}_t^{bi}(\underline{M}_j) = \underline{H}_{ti}^{sc} \tag{4}$$

$$\text{over } A_i \ (i = 1, 2)$$

For 'A'region, we can use the image method[2](see Fig.3) and so,we have

$$\underline{H}_z(\underline{\rho}) = \frac{\epsilon}{4j} \sum_i \int_{A_i} 2\underline{M}_i(\underline{\rho}') H_0^{(2)}(K \mid \underline{\rho} - \underline{\rho}' \mid) \, dx \tag{5}$$

where, $\underline{\rho} = \underline{u}_x x + \underline{u}_y y$ is the field point and $\underline{\rho}' = \underline{u}_x x'$ is the source point, and A_i is the area of the ith aperture. The magnetic field is

$$\underline{H}_z^a = -\frac{K}{4\eta} \int_d^{d+a} 2\underline{M}_1(x') H_0^{(2)}(K \mid \underline{\rho} - \underline{\rho}' \mid) \, dx' - \frac{K}{4\eta} \int_{-d-b}^{-d} 2\underline{M}_2(x') H_0^{(2)}(K \mid \underline{\rho} - \underline{\rho}' \mid) \, dx' \tag{6}$$

$$(d \le x \le d + a) \ (y = 0)$$

over aperture 1, and

$$\underline{H}_z^a = -\frac{K}{4\eta}\int_d^{d+a} 2\underline{M}_1(x')H_0^{(2)}(K \mid \underline{\rho} - \underline{\rho}' \mid)\, dx' - \frac{K}{4\eta}\int_{-d-b}^{-d} 2\underline{M}_2(x')H_0^{(2)}(K \mid \underline{\rho} - \underline{\rho}' \mid)\, dx' \tag{7}$$

$$(-d - b \leq x \leq -d) \; (y = 0)$$

over aperture 2, where $K = \omega\sqrt{\mu_a \epsilon_a}$

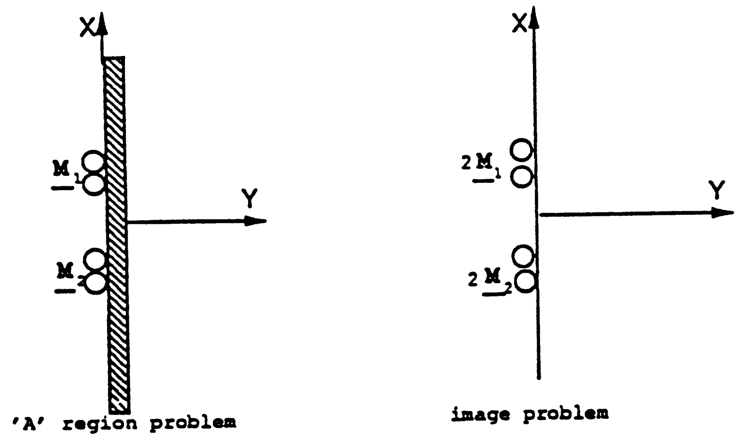


Figure 3: Image problem for region 'A'

3. Imitation of the loaded apertures

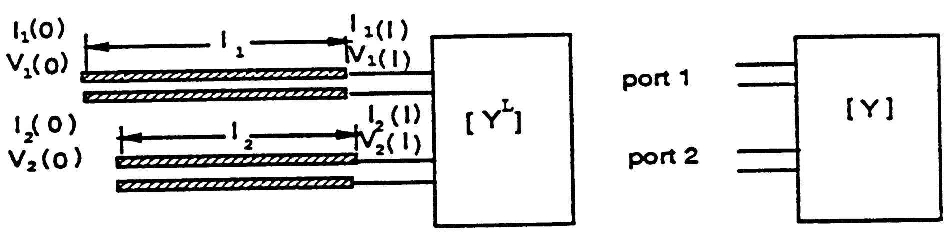
In 'B' region where $y > 0$, there are parallel waveguides connected to each aperture . At the other end the waveguides are interconnected by a microwave network as shown in Fig.2(b).

The transmission lines and microwave network form a new equivalent network with the apertures as loads(see Fig.4)[12,14]. The elements of this new equivalent network can be derived from the basic definition based on the voltages and currents at each aperture.

3.1 Transmission Mode Admittance Matrix

We assume only one waveguide mode is propagating mode in each waveguide. First, we use transmission line theory to calculate the equivalent network parameters. For the transmission line equation We use the following form,

$$\begin{cases} V_n(y) = V_0 \cosh K_n y - I_0 Z_0 \sinh K_n y \\ I_n(y) = I_0 \cosh K_n y - \frac{V_0}{Z_n} \sinh K_n y \end{cases} \tag{8}$$



(a) 'B' region problem (b) equivalent problem

Figure 4: The equivalent network

Where, K_n is the transmission line propagation constant, V_0 and I_0 are the voltage and current at the beginning of the waveguide, and Z_n is the characteristic impedance of the waveguide. We define the admittance of the equivalent network by

$$Y_{mp} = \frac{I_n}{V_p}|_{V_n=0 \,\&\, n \neq p} \tag{9}$$

Through appropriate deductions, we have the elements of the new equivalent admittance matrix [Y], as follows

$$\begin{pmatrix} Y \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{pmatrix} \tag{10}$$

$$\begin{aligned} Y_{11} = A_1 \quad Y_{12} = \tfrac{B_1}{\Delta_2} \\ Y_{21} = A_2 \quad Y_{22} = \tfrac{B_2}{\Delta_2} \end{aligned} \tag{11}$$

$$\Delta_1 = \Delta_2 = \begin{vmatrix} \cosh K_1 l_1 + Z_{c1} Y_{11}^L \sinh K_1 l_1 & Y_{12}^L Z_{c2} \sinh K_2 l_2 \\ Z_{c1} Y_{21}^L \sinh K1 l_1 & \cosh K_2 l_2 + Z_{c2} Y_{22}^L \sinh K_2 l_2 \end{vmatrix} \tag{12}$$

$$A_1 = \begin{vmatrix} \frac{1}{Z_{c1}} \sinh K_1 l_1 + Y_{11}^L \cosh K_1 l_1 & Z_{c2} Y_{12}^L \sinh K_2 l_2 \\ Y_{21}^L \cosh K_1 l_1 & \cosh K_2 l_2 + Z_{c2} Y_{22}^L \sinh K_2 l_2 \end{vmatrix} \tag{13}$$

$$A_2 = \begin{vmatrix} \cosh K_1 l_1 + Z_{c2} Y_{11}^L \sinh K_1 l_1 & \frac{1}{Z_{c1}} \sinh K_1 l_1 + Y_{11}^L \cosh K_1 l_1 \\ Z_{c1} Y_{21}^L \sinh K_1 l_1 & Y_{21}^L \cosh K_1 l_1 \end{vmatrix} \tag{14}$$

$$B_1 = \begin{vmatrix} Y_{12}^L \cosh K_2 l_2 & Z_{c2} Y_{12}^L \sinh K_2 l_2 \\ \frac{1}{Z_{c2}} \sinh K_2 l_2 + Y_{22}^L \cosh K_2 l_2 & \cosh K_2 l_2 + Z_{c2} Y_{22}^L \sinh K_2 l_2 \end{vmatrix} \tag{15}$$

$$B_2 = \begin{vmatrix} \cosh K_1 l_1 + Z_{c1} Y_{11}^L \sinh K_1 l_1 & Y_{12}^L \cosh K_2 l_2 \\ Z_{c1} Y_{21}^L \sinh K_1 l_1 & \frac{1}{Z_{c2}} \sinh K_2 l_2 + Y_{22}^L \cosh K_2 l_2 \end{vmatrix} \tag{16}$$

3.2 Attenuation Mode Admittance Matrix

For the attenuated waves, where exists no coupling, the admittance matrix of the attenuation modes is a diagonal and the elements are the characteristic admittances of the two waveguides[6] given as following:

$$Y_{ii} = \frac{1}{Z_{ci}} \qquad\qquad Y_{ij} = 0\ (i \neq j)\ (i,j \geq 2) \tag{17}$$

4. The Moment Method Version

In order to obtain an approximate solution, we use the method of moments[1].

We choose N expansion functions in each aperture and assume that the linear combination

$$\underline{M}_z^j = \sum_{n=1}^{N_j} V_n^j \underline{M}_n^j \qquad\qquad (j = 1,2) \tag{18}$$

approximates the equivalent magnetic current in A_j (FIg2). Substituting (18) into (4) and using the linearity of the H_t operators, we obtain,

$$\sum_{j=1}^{2}[-\sum_{n=1}^{N_j} V_{na}^{ij} H(\underline{M}_n^j) - \sum_{n=1}^{N_j} V_{nb}^{ij} H(\underline{M}_n^j)] = \underline{H}_t^{sc} \qquad\qquad over\ A_i\ (i = 1,2) \tag{19}$$

choose the symmetric product

$$\langle F, G\rangle_j = \int_{A_i} (F \cdot G)\, dx \qquad\qquad (j = 1,2) \tag{20}$$

and using Galerkin's method with pulse basis functions, that is, the test functions are

$$\{M_n^j, \quad n = 1,2,\cdots N_j\} \qquad\qquad (j = 1,2) \tag{21}$$

We use further pulse basis functions on the mode expansion. We set,

$$W_n^j = M_n^j = \Psi_n^j = \sum_{k_j=1}^{N_j} A_{k_j,n}^j P_{k_j,n}^j(x) \qquad\qquad over\ A_j \tag{22}$$

here Ψ_n^j is the normalized mode function in j-th waveguide, $P_{k_j,n}^j(x)$ is pulse function, and N_j is the total number of pulse expansion functions. Apply the symmetric product to (4) and obtain

$$\langle -W, H_z^a(\underline{M})\rangle_j + \langle -M, H_z^b(\underline{M})\rangle_j = \langle W, H_z^{sc}\rangle_j \qquad over\ A_j. \tag{23}$$

putting (19),(21) and (22) into (23), we have

$$\langle \sum_{m=1}^{N_i} M_m^i, \sum_{j=1}^{2}\sum_{n=1}^{N_j} V_{na}^{ij} H(M_n^j)\rangle_i + \langle \sum_{m=1}^{N_i} M_m^i, \sum_{j=1}^{2}\sum_{n=1}^{N_j} V_{nb}^{ij} H(M_n^j)\rangle_i = \langle \sum_{m=1}^{N_i} M_m^i, H_t^{sc}\rangle_i \tag{24}$$

$$over\ A_i\ (i = 1, 2)$$

This equation can be rearranged to a matrix equation,

$$\{\begin{pmatrix} Y^a \end{pmatrix} + \begin{pmatrix} Y^b \end{pmatrix}\}\vec{V} = \vec{I} \tag{25}$$

The elements of $\begin{pmatrix} Y^a \end{pmatrix}$ and $\begin{pmatrix} Y^b \end{pmatrix}$ are

$$Y_{mn}^a = \langle M_m^i, H^a(M_n^j)\rangle_i \qquad (over\ A_i) \qquad (i = 1, 2) \tag{26}$$

$$Y_{mn}^b = -\langle M_m^i, H^b(M_n^j)\rangle_i \qquad (over\ A_i) \qquad (i = 1, 2) \tag{27}$$

Substitute from (22) and use the linearity of the operator and the symmetry product.

The matrix elements then become

$$Y_{mn}^a = \langle \sum_{k_i=1}^{K_i} A_{k_i,m}^i P_{k_i,m}^i(x), H^a(\sum_{k_j=1}^{K_j} A_{k_j,n}^j P_{k_j,n}^j(x))\rangle_i = \sum_{k_i=1}^{K_i}\sum_{k_j=1}^{K_j} A_{k_i,m}^i A_{k_j,n}^j \langle P_{k_i,m}^i(x), H^a(P_{k_j,n}^j(x))\rangle_i \tag{28}$$

Where

$$P_{k_i,m}^i(x) = \begin{cases} 1 & on\ \Delta x_i \\ 0 & elsewhere \end{cases} \qquad for\ test\ function\ on\ A_i$$

$$P_{k_j,n}^j(x) = \begin{cases} 1 & on\ \Delta x_j \\ 0 & elsewhere \end{cases} \qquad for\ test\ function\ on\ A_j$$

$A^i_{k_i,m}$ and $A^j_{k_j,n}$ are the expansion coefficients for the mode function Ψ_m and $\Psi_n$in the pulse basis. The mode function are

$$\Psi_n = \begin{cases} \frac{1}{\sqrt{D}} & n = 0 \\ \sqrt{\frac{2}{D}} \cos \frac{n\pi(x-s)}{D} & n \neq 0 \end{cases} \tag{29}$$

Where $\hat{x}_i$ is the middle point of Δx_i . Substituting (6) and (7) into (28), we have

$$Y^{a11}_{mn} = \sum_{k_i=1}^{K_1} \sum_{k_j=1}^{K_1} A^1_{k_i,m} A^1_{k_j,n} \int_{d+(k_i-1)\Delta_1}^{d+k_i\Delta_1} dx \int_{d+(k_j-1)\Delta_1}^{d+k_j\Delta_1} \frac{K}{2\eta} H_0^{(2)}(K|x-x'|)\, dx' \tag{30}$$

$$Y^{a12}_{mn} = \sum_{k_i=1}^{K_1} \sum_{k_j=1}^{K_2} A^1_{k_i,m} A^2_{k_j,n} \int_{d+(k_i-1)\Delta_1}^{d+k_i\Delta_1} dx \int_{-d-b+(k_j-1)\Delta_2}^{-d-b+k_j\Delta_2} \frac{K}{2\eta} H_0^{(2)}(K|x-x'|)\, dx' \tag{31}$$

$$Y^{a21}_{mn} = \sum_{k_i=1}^{K_2} \sum_{k_j=1}^{K_1} A^2_{k_i,m} A^1_{k_j,n} \int_{-d-b+(k_i-1)\Delta_2}^{-d-b+k_i\Delta_2} dx \int_{d+(k_j-1)\Delta_1}^{d+k_j\Delta_1} \frac{K}{2\eta} H_0^{(2)}(K|x-x'|)\, dx' \tag{32}$$

$$Y^{a22}_{mn} = \sum_{k_i=1}^{K_2} \sum_{k_j=1}^{K_2} A^2_{k_i,m} A^2_{k_j,n} \int_{-d-b+(k_i-1)\Delta_2}^{-d-b+k_i\Delta_2} dx \int_{-d-b+(k_j-1)\Delta_2}^{-d-b+k_j\Delta_2} \frac{K}{2\eta} H_0^{(2)}(K|x-x'|)\, dx' \tag{33}$$

Here $\Delta_1 = \frac{a}{K_1}$ and $\Delta_2 = \frac{b}{K_2}$ are the uniform division for the pulse expansion.

$$\begin{aligned} A^1_{k_i,m} &= \begin{cases} \sqrt{\frac{1}{a}} & m = 0 \\ \sqrt{\frac{2}{a}} \cos \frac{m\pi(\hat{x}_i-d)}{a} & m \neq 0 \end{cases} \quad & A^2_{k_i,m} &= \begin{cases} \sqrt{\frac{1}{b}} & m = 0 \\ \sqrt{\frac{2}{b}} \cos \frac{m\pi(\hat{x}_i-d)}{b} & m \neq 0 \end{cases} \\ A^1_{k_j,n} &= \begin{cases} \sqrt{\frac{1}{a}} & n = 0 \\ \sqrt{\frac{2}{a}} \cos \frac{n\pi(\hat{x}_j-d)}{a} & n \neq 0 \end{cases} \quad & A^2_{k_j,n} &= \begin{cases} \sqrt{\frac{1}{b}} & n = 0 \\ \sqrt{\frac{2}{b}} \cos \frac{n\pi(\hat{x}_j-d)}{b} & n \neq 0 \end{cases} \end{aligned} \tag{34}$$

The excitation vector is

$$\vec{I^i} = (\langle \underline{M}^i_m, \underline{H}^{sc}_t \rangle) \tag{35}$$

where $\underline{H}^{sc}_t$ is the field when the apertures covered by metal plane. Using image methods, we have

$$\underline{H}^{sc}_t = 2\, e^{-jkx\cos\phi_{in}} \underline{u}_x.$$

At last, we have

$$\vec{I} = \begin{pmatrix} \vec{I}_1 \\ \vec{I}_2 \end{pmatrix}$$

and

$$\vec{I}_1 = (\langle \underline{W}^1_m, \underline{H}^{sc}_t \rangle)_{1 \times k_i}$$

$$\vec{I}_2 = (\langle \underline{W}^2_m, \underline{H}^{sc}_t \rangle)_{1 \times k_j}$$

Using mode expansion and pulse basis, we obtain

$$I^1_{k_i} = \sum_{k_m=1}^{K_m} A^1_{k_i,m} \int_{d+(k_m-1)\Delta_1}^{d+k_m\Delta_1} 2\, e^{-jKx\cos\Phi_{in}}\, dx \tag{36}$$

$$I^2_{k_j} = \sum_{k_m=1}^{K_m} A^2_{k_j,m} \int_{-d-b+(k_m-1)\Delta_2}^{-d-b+k_m\Delta_2} 2\, e^{-jKx\cos\Phi_{in}}\, dx \tag{37}$$

On integrating, we have

$$I^1_{k_i} = \sum_{k_m=1}^{K_m} 2A^1_{k_i,m} \frac{\sin(K\Delta_1 \cos\phi_{in})}{K\Delta_1 \cos\phi_{in}}\, e^{-jK\hat{x}\cos\Phi_{in}} \tag{38}$$

$$I^2_{k_j} = \sum_{k_m=1}^{K_m} 2A^2_{k_j,m} \frac{\sin(K\Delta_2 \cos\phi_{in})}{K\Delta_2 \cos\phi_{in}}\, e^{-jK\hat{x}\cos\Phi_{in}} \tag{39}$$

Solving equation(25), we get the coefficient $[V]$ and then using (18) and (6), we get the mathematic model to imitate the electromagnetic scattering field.

5. Computational Models

This section describes both sequential and parallel computational models. The sequential code is around 1000 lines of Fortran statements. The sequential code is written in standard Fortran 77. The parallel code is available in two versions, Fortran 90 version and CM Fortran version.

5.1 Sequential Program

Figure 5 shows the flow chart of the algorithm. We run the sequential code on SPARC IPC station . It needs 39.13 hours to finish the calculations on an array of dimension (512,512,4,10,10).

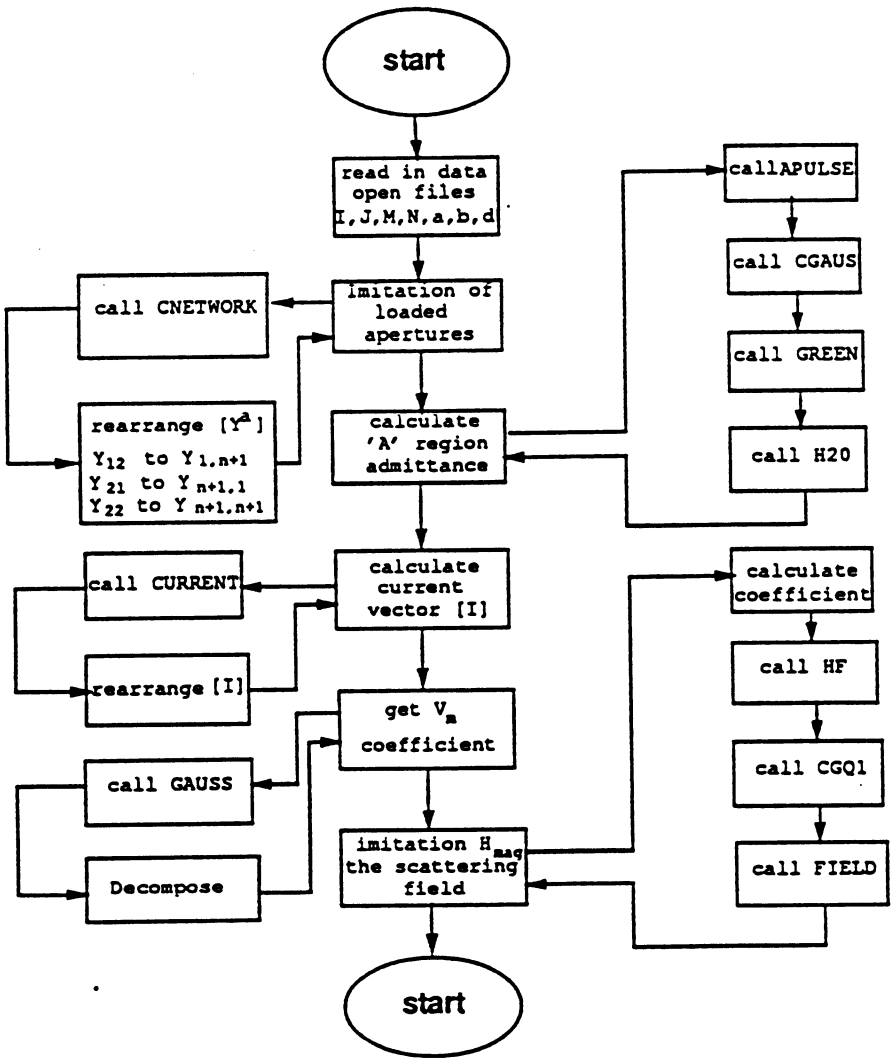


Figure 5: The sequential program algorithm

5.2 The Connection Machine CM-2 Architecture

The CM-2 Connection Machine system [3] [11] is a massively data parallel computer with 65536 processors. Each processor has 1 Megabits of local memory, so the machine has an overall memory capacity of 8 Gigabytes. The processors (and their associated memories) are arranged in hardware with 16 to a chip. In addition, every "node," consisting of a pair of chips(32 processors), is supported by floating-point accelerator[8].

The CM-2 operates in "single-instruction multiple-data"(SIMD) mode; that is, an identical instruction set is broadcast to each processor. It is thus very efficient for tasks that can be solved by simultaneous operation on all of the data present. The CM-2 is furthermore characterized by a very sophisticated communications network linking all of its processors. For all of the above reasons, the CM-2 is very well-suited for many problems in computational science and engineering including simulations of electromagnetic fields.

The CM-2 Connection Machine system uses a conventional front-end computer. The front-end executes the control structure of programs, issuing commands to the CM-2 processors whenever necessary.

5.3 Implementation on the CM-2

The performance analysis of the sequential code showed that the core calculations in the main program are the evaluations of the elements of the 'A' region admittance matrix.

[3]Connection Machine is a registered trademark of Thinking Machines Corporation

The basic premise of these calculations is that they can be performed in parallel since they are completely independent.

For example, to calculate the elements of the matrix for an array of 512x512x4x10x10, the Hankel function needs to be evaluated 1.048576 10^8 times. To do this on a CM-2 with 16384 processors the Hankel function will be evaluated by each processor simultaneously 6400 times only. In other parts of the code, we took all opportunities to use the efficient assembly coded CMSSL (Connection Machine Scientific Subroutine Library).

The rest of the code is implemented using the array syntax that maps naturally on the CM-2.

6. Examples

We calculate the following cases with different waveguide widths and distances, and different waveguide lengths with various loads.

In the following cases, we calculate [I],[V],[Y^a], then plot the field pattern. We use 'MH-pattern' to express the radiation field pattern produced by the equivalent magnetic currents. The total field strength is the incident field plus the reflected field plus the radiation field. The scattered field is scattered from a complete body plus the radiation field. We take the wavelength of incident wave to be one meter.

Case 1:

The waveguide widths are the same,i.e., a=b=0.45λ. The length of the waveguides are the same, $L_1 = L_2 = 0.25\lambda$. The distance is $2d = 1\lambda$. The microwave network matches the two waveguides, i.e. $Y_1 = Y_2 = \frac{1}{377}$. This is shown in Fig.6 and 'MH-pattern' is plotted in Fig.7.

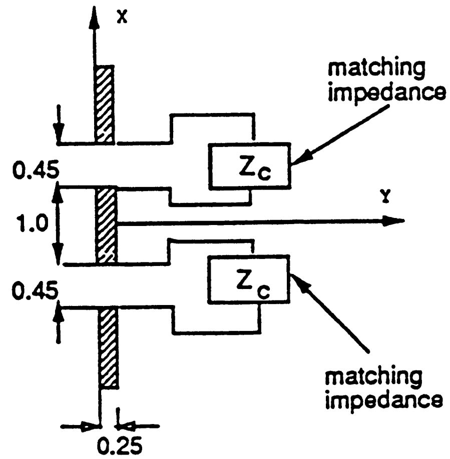


Figure 6: The original problem

<u>Case 2</u>:

This case is the same as case 1 except that in the case the distance apart is $2d = 0.2\lambda$. The problem is shown in Fig.8, and the result is shown in Fig.9.

<u>Case 3</u>:

In this case the apertures are wider: $a = b = 0.45\lambda$ $2d = 1.\lambda$ and the microwave network matches the waveguides, just as in case 1. The result pattern is shown in Fig.10.

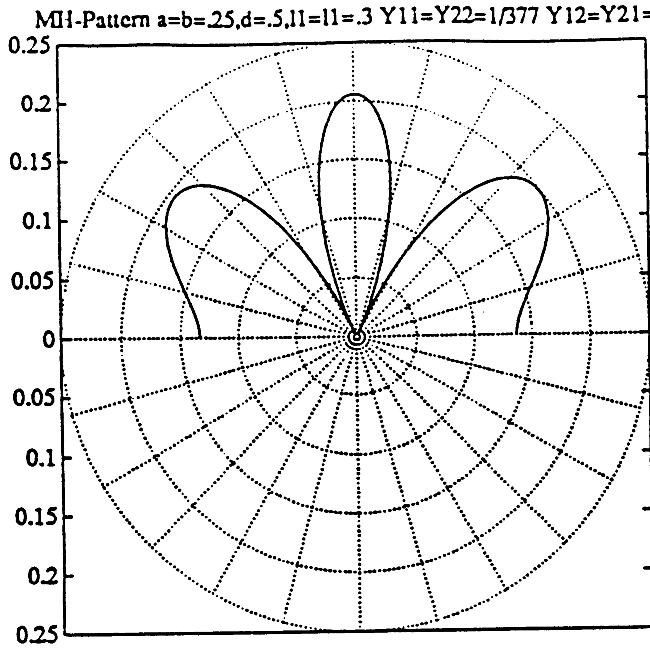


Figure 7: MH-Pattern when the apertures are matched

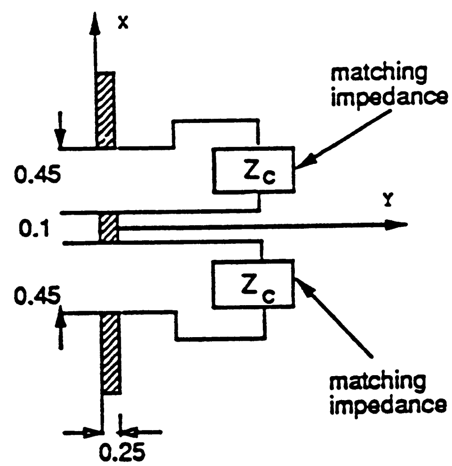


Figure 8: The original problem

Case 4:

In this case, the conditions are almost the same as case 1, but the aperture widths are not the same: $a = 0.25\lambda$ and $b = 0.1\lambda$. The result is shown in Fig. 11.

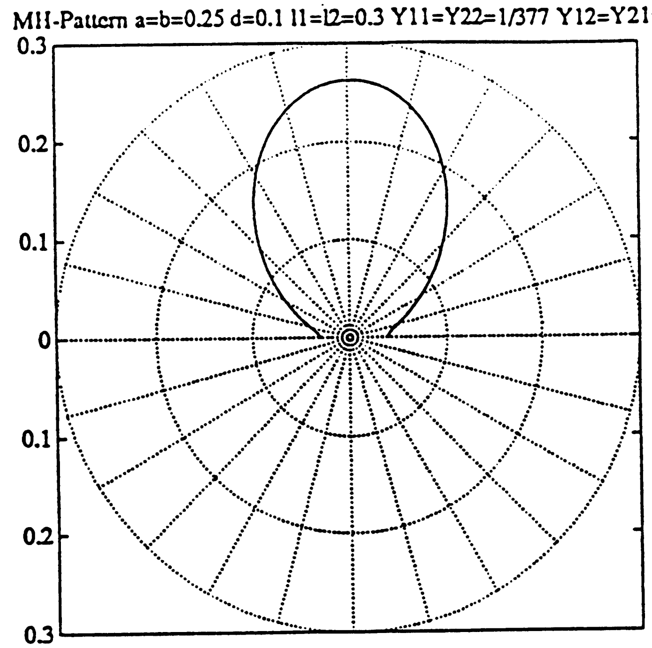


Figure 9: MH-Pattern when the aperture distance apart is small

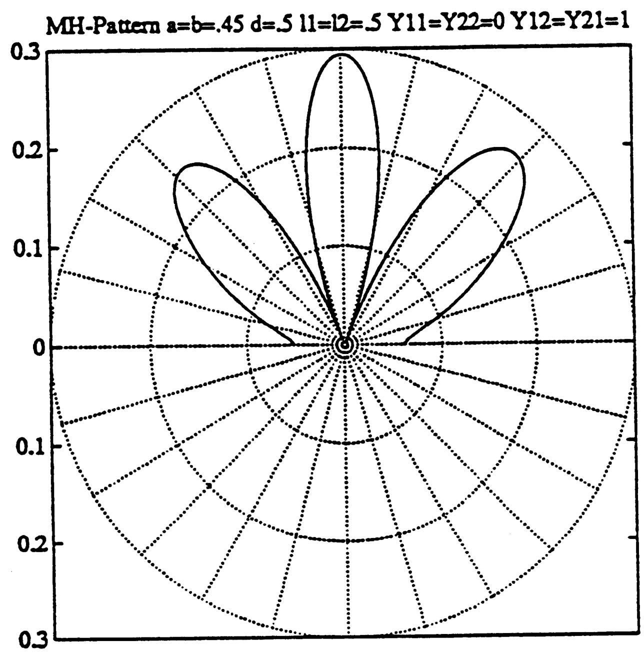


Figure 10: MH-Pattern when the aperture withs are wider

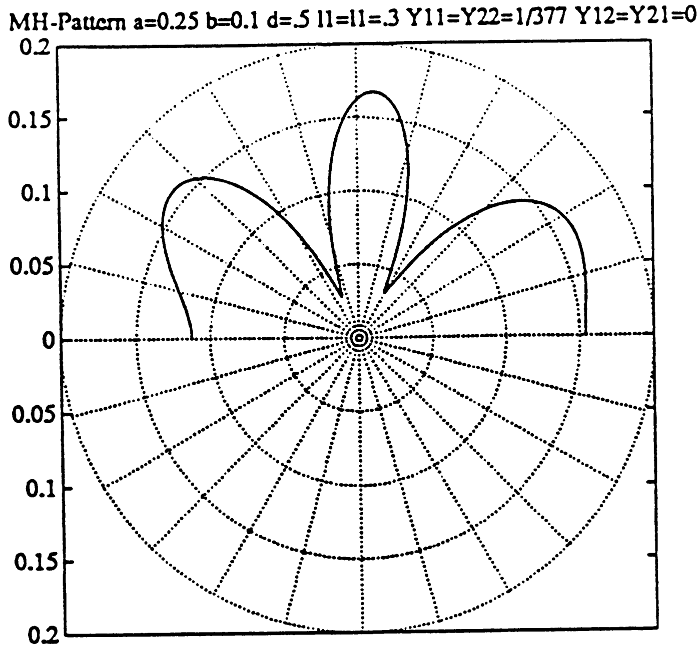


Figure 11: MH-Pattern when the aperture widths are different

Case 5:

In this case, the apertures are connected directly, i.e. $Y_{11} = Y_{22} = 0$ and $Y_{12} = Y_{21} = 1$. The structure is shown in Fig.12 and the result pattern is shown in Fig.13.

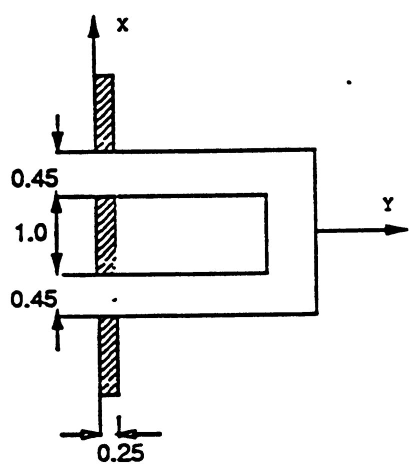


Figure 12: MH-Pattern when the apertures are connected directly

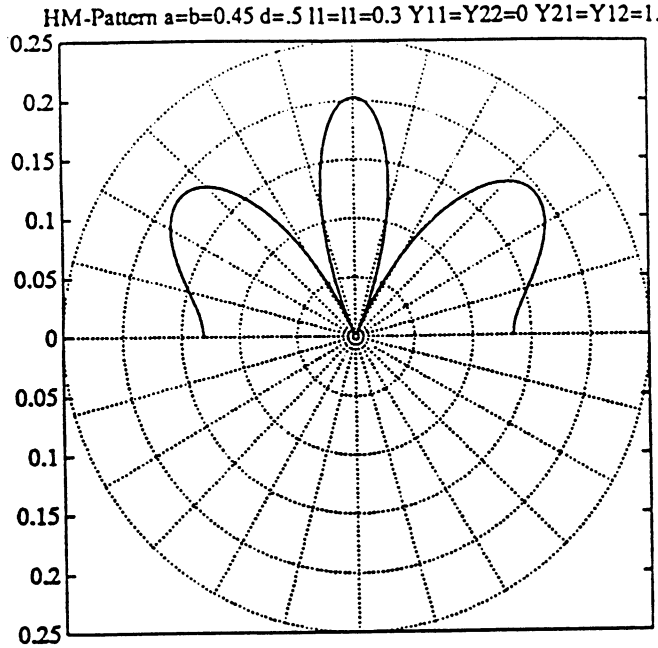


Figure 13: MH-Pattern when the apertures are dtrected connected

7. Conclusion

The Moment Method for simulating the electromagnetic scattering from conductors containing loaded slots was coded into a sequential Fortran 77 code, parallel Fortran 90 code and CM Fortran code. The CM Fortran code was applied to solve several test codes. The converted codes were verified by producing exactly the same results as the sequential one.

The main results of converting the code are as follows:

1. A typical case of the studied cases took 35.14 seconds elapsed time on CM-2 when using the Fortran 90 version. It took even shorter elapsed time, when using the CM Fortran version. How much success does this represents such a question can be easily answered by comparing these results with the 39.13 hours it takes the sequential code to solve a similar case on the SPARC station.

2. Algorithm analysis showed that the Moment Method has a lot of parallel opportunities and maps naturally on the CM-2. This is because of the use of expansion functions and test functions that are completely independent.

From the results of the five cases, we come to the following conclusions:

(1) The radiation fields produced by equivalent magnetic currents in the two apertures are very like the fields of two magnetic dipoles located at the apertures.

(2) The wider the apertures widths are, the stronger the field produced by the magnetic currents on the apertures is.

(3) The transmission mode is the dominant mode in determining the field produced by the two apertures. This is because the function form of the tangential electric field in an aperture is close to that of the propagating mode[5].

(4) The field pattern depends on the distance between the two apertures(see Fig.10 and Fig.11).

(5) The 'A' region admittances are dominant. So that the affect of the microwave network on the field is small compared to that of the 'A' region admittances.

(6) If the distance between the two apertures is larger, the 'MH-Pattern' will have more loops than the examples.

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