SIMULATION OF ELECTROMAGNETIC FIELDS IN NRD GUIDE LEAKY-WAVE ANTENNA BY SPATIAL NETWORK METHOD

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1. Introduction

Recently, for many kinds of engineering problems, numerical analysis methods have become very useful with the remarkable development of the digital computer, especially the super computer. For the numerical analysis of electromagnetic field problems, the finite-element method (FEM) and the boundary element method (BEM) take their place for the two-dimensional analysis at the steady state. On the other hand, the full-wave or vector analysis is essential in the three-dimensional case. For this purpose, some finite-difference methods such as the finite-difference time-domain method (FD-TD) and the transmission-line matrix method (TLM) have been proposed, and they are well known to have many merits.

We have recently proposed a numerical vector analysis method in a three-dimensional space and time domain, which is called as the Spatial Network Method. This method is based on both the equivalent circuit of Maxwell's equations and the formulation by Bergeron's method in the time domain. As the nodal equation at each node in this formulation is independent at each time step, the partition of an analyzed region becomes very easy. This property is very essential to avoid a limit of the main memory capacity of used computer for the simulation of large scale problems.

This paper describes that the method can perform the high speed computaion by using the extended memory of the super computer for simulating the propagation and the radiation characteristics of the NRD guide leaky-wave antenna.

2. Spatial Network Method (1)-(5)

Fig. 1 shows the three-dimensional network constructed by nodes and lines with length Δd, which are interpreted as the points where the continuity of currents occurs and the one-dimensional transmission lines, respectively. In table 1, the fundamental correspondence between thefield variables in Maxwell's equations and the equivalent circuit variables in the network is shown for every kind of node in the network. The nodal equation at this method is calculated by use of the values previously obtained at one time step ago in adjacent nodes. So at each time step, this independency of calculation to othernodes enables to part the whole analyzed region to the sub- regions of the arbitary size matched to the capacity of the main memory of the used computer.

3. NRD guide leaky-wave antenna (6)-(7)

The asymmetrical NRD guide leaky wave antenna has been proposed. Antennas of this type have a simple structure and can alternate beam width and direction. But the structure of this guide produces very complicated hybrid leaky modes. Fig. 2 shows the analyzed model of the asymmetrical NRD guide.

In the figure the dimensions are normalized by the spatial interval, refered to as Δd. The relative dielectric constant εr=2.56. The asymmetrical structure of this guide is realized by the air gap of $2\Delta d$ above the dielectric. The length of dimension z is 28 free-space wavelengths. The transverse conductor plate length C is variable. The sinusoidal wave, of wavelength $40\Delta d$, is excited uniformly by the electric field Ex at the dielectric in the input plane. All boundaries of the analyzed region except the conductor and the input are terminated by matching conditions. The observed plane of the instantaneous waveform is arranged as shown by the broken line in Fig. 2. Fig. 3 shows instantaneous wave form for electric field Ey, and Fig. 4 gives the wavenumber spectrum obtained by Fourier-transforming the waveform in Fig. 3. The spectrum seems to have three peaks, which correspond to the three modes in this NRD guide. The peak indicated by the normalized propagation constant β/k_0=0.67 especially corresponds to the leaky-wave mode because of its having a comparably large magnitude on the aperture plane. The other leaky mode is also indicated by the normalized propagation constant 0.89.

On the other hand, it is known that the attenuation constant of these leaky mode can be changed with C because of the varying conditions of reflection on the aperture. Using this property, we can in turn vary the half-power beamwidth of the radiation patern. In Fig. 5, the radiation patterns for two different plate width are presented. These patterns are calculated from the electric field distribution of Ey on the aperture plane. Fig. 5a shows the radiation pattern for the case $C=1.0\lambda_0$, corresponding to the strongrt attenuating condition. Fig. 5b shows the pattern for the case of $C=1.35\lambda_0$, corresponding to the weaker attenuating condition. Comparing these results, it is shown that the latter has the sharper radiation pattern than that of the former. Then the relation between the beamwidth and the attenuating condition for the radiation is ascertained. Fig. 6 shows the beam direction by changing the wave length r0 of the input wave. As λ_0 increases from $35\Delta d$ to $44\Delta d$, the beam direction varies between about 8° and 72°.

4. Use of the extended memory

In the simulation of the above NRD guide, the anlyzed region has become very larger as the dimension of z- direction is lengthened to obtain the sufficient accuracy in caluculating both the wavenumber spectrum by Fourier-transform and the radiation paterns. Therefore the whole anlyzed region cannot be stored at once in the main memory of the used computer. Then we divide the region to some sub-regions and stored only one sub-region in the main memory, and others are stored in the extended memory. The extended memory is constructed by dynamic memories and has the maximum transfer speed of 2GB/sec and 0.5GB/sec in the super computer HITAC S820/80 and S810/10, respectively. The transfer speed increases as a volume of the transfered data at once increases. But, the volume is limited by the capacity of main memory. In this analysis, three cases are comuputed to examine the performance of computing. The results are shown in Table 2. These results show clearly the relation between the transfered date volume and its speed.

5. Conclusion

In this paper, We describe the simulation of complicated electromagnetic fields by the Spatial Network Method. The radiation characteristics of the NRD guide leaky-wave antenna, such as the beam width and the beam direction, are obtained. It has become clear that the effective usage of the extended memory is indispensable to realize the high speed calculation of a large scale problem by the super computer.

6. REFERENCES

(1) N. Yoshida, I. Fukai and J. Fukuoka:"Transient Analysis of Three-Dimensional Electromagnetic Field by Nodal Equation" Trans. IECE Japan, J63-B, 9, pp.876-883 (Sept. 1980).

(2) S. Koike, N. Yoshida and I. Fukai:"Transient Analysis of Microstrip Line on Anisotropic Substrate in Three-Dimensional Space," IEEE Trans. on Microwave Theory and Tech., MTT-36, 1, pp.34-43 (Jan. 1988).

(3) T. Kashiwa, N. Yoshida and I. Fukai:"Three-Dimensional Analysis of Patch Antenna by Bergeron's Method," Trans. IEICE Japan, J71-B, 4, pp.576-584 (April 1988).

(4) T. Kashiwa, N. Yoshida and I. Fukai:"Transient Analysis of a Magnetized Plasma in Three-Dimensional Space," IEEE Trans. on Antennas & Propag., AP-36, 8, pp.1096-1105 Aug. 1988).

(5) T. Aoto, Y. Kakimi, N. Yoshida and I. Fukai:"Transient Analysis of Near Field for Conductive Pillar with Thin Type Absorber," IEEE Trans. on Antennas & Propag. AP-37, 4 (April 1989).

(6) K. Terashima, N. Yoshida and I. Fukai:"Three-Dimensional Analysis of Electromagnetic Fields for NRD Guide with Air Gap and Finite-Metal Plane Width," Trans. IEICE Japan, J71-C, 7, pp.1051- 1062 (July, 1988).

(7) K. Terashima, N. Yoshida and I. Fukai:"Analysis of Radiation Characteristics of NRD Guide Leaky-Wave Antenna by Spatial Network Method," Electronics Lett. 1st Sept., 24, 18, pp.1164-1165 (Sept. 1988).

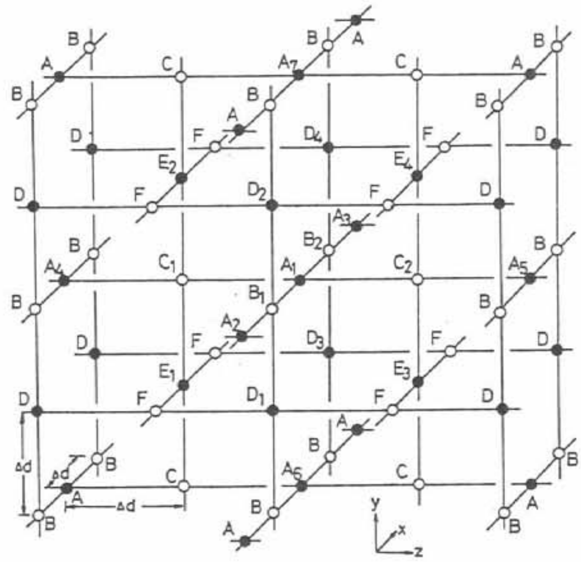

Fig. 1 Three-Dimensional Lattice Network

	Electric node			Magnetic node	
	Maxwell's equations	Variables		Maxwell's equations	Variables
Ak	$\frac{\partial Hx}{\partial z}-\frac{\partial Hz}{\partial x}=\varepsilon_0\frac{\partial Ey}{\partial t}$	$Vy \equiv Ey$	Fk	$\frac{\partial Ex}{\partial z}-\frac{\partial Ez}{\partial x}=-\mu_0\frac{\partial Hy}{\partial t}$	$V_y^* \equiv Hy$
	$-\frac{\partial Ey}{\partial z}=-\mu_0\frac{\partial Hx}{\partial t}$	$Iz \equiv -Hx$		$-\frac{\partial Hy}{\partial z}=\varepsilon_0\frac{\partial Ex}{\partial t}$	$I_z^* \equiv Ex$
	$\frac{\partial Ey}{\partial x}=-\mu_0\frac{\partial Hz}{\partial t}$	$Ix \equiv Hz$		$\frac{\partial Hy}{\partial x}=\varepsilon_0\frac{\partial Ez}{\partial t}$	$I_x^* \equiv -Ez$
Dk	$\frac{\partial Hz}{\partial y}-\frac{\partial Hy}{\partial z}=\varepsilon_0\frac{\partial Ex}{\partial t}$	$Vx \equiv Ex$	Bk	$\frac{\partial Ey}{\partial x}-\frac{\partial Ex}{\partial y}=-\mu_0\frac{\partial Hz}{\partial t}$	$V_z^* \equiv Hz$
	$\frac{\partial Ex}{\partial z}=-\mu_0\frac{\partial Hy}{\partial t}$	$Iz \equiv Hy$		$\frac{\partial Hz}{\partial y}=\varepsilon_0\frac{\partial Ex}{\partial t}$	$I_y^* \equiv -Ex$
	$-\frac{\partial Ex}{\partial y}=-\mu_0\frac{\partial Hz}{\partial t}$	$Iy \equiv -Hz$		$-\frac{\partial Hz}{\partial x}=\varepsilon_0\frac{\partial Ey}{\partial t}$	$I_x^* \equiv Ey$
Ek	$\frac{\partial Hy}{\partial x}-\frac{\partial Hx}{\partial y}=\varepsilon_0\frac{\partial Ez}{\partial t}$	$Vz \equiv -Ez$	Ck	$\frac{\partial Ez}{\partial y}-\frac{\partial Ey}{\partial z}=-\mu_0\frac{\partial Hx}{\partial t}$	$V_x^* \equiv -Hx$
	$\frac{\partial Ez}{\partial y}=-\mu_0\frac{\partial Hx}{\partial t}$	$Iy \equiv -Hx$		$\frac{\partial Hx}{\partial z}=\varepsilon_0\frac{\partial Ey}{\partial t}$	$I_z^* \equiv Ey$
	$-\frac{\partial Ez}{\partial x}=-\mu_0\frac{\partial Hy}{\partial t}$	$Ix \equiv Hy$		$-\frac{\partial Hx}{\partial y}=\varepsilon_0\frac{\partial Ez}{\partial t}$	$I_y^* \equiv -Ez$
dielectric constant	$C_0=\varepsilon_0/2$		dielectric constant	$L_0^*=\varepsilon_0/2$	
permeability	$L_0=\mu_0/2$		permeability	$C_0^*=\mu_0/2$	
polarization	$\Delta C=\varepsilon_0\chi e/2\cdot\Delta d$		magnetization	$\Delta C^*=\mu_0\chi m/2\cdot\Delta d$	
conductivity	$G=\sigma/2\cdot\Delta d$		magnetic current loss	$G^*=\sigma^*/2\cdot\Delta d$	
magnetization	$\Delta L=\mu_0\chi m/2\cdot\Delta d$		polarization	$\Delta L^*=\varepsilon_0\chi e/2\cdot\Delta d$	

Table 1 Correspondence between Variables

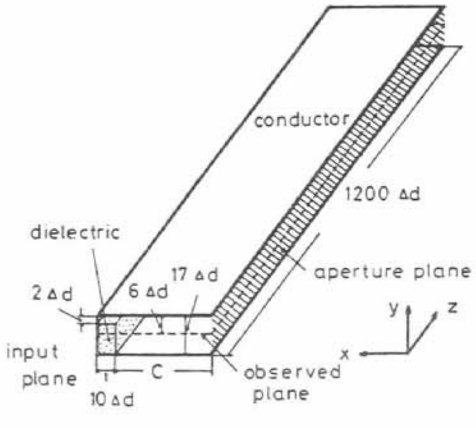

Fig. 2 Analyzed Model of asymmetrical NRD guide

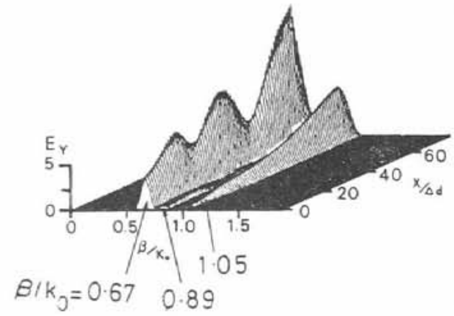

Fig. 4 Wave number Spectrum for Fig. 3

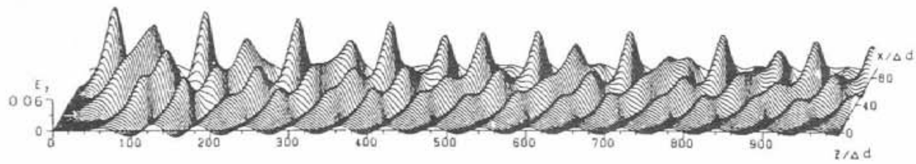

Fig. 3 Instantaneous Field Distribution of Ey

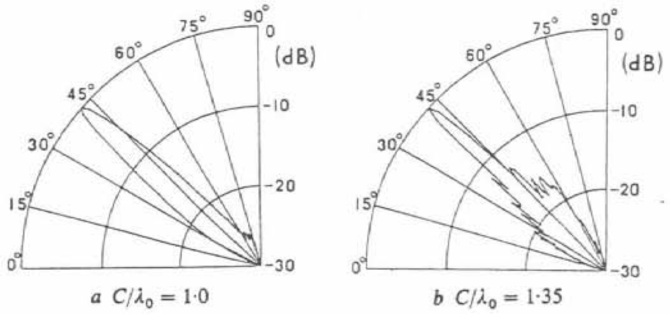

Fig. 5 Radiation Patterns for each plate width C

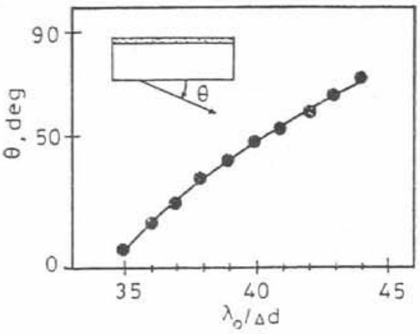

Fig. 6 Change of beam direction by wavelength

Cases		Computatin Time per one Time Step (Transformed to speed of case 1)	S810/10 / S820/80
1	Region 24MB Only by Main Memory	0.0953sec (S810/10) 0.0117sec (S820/80)	8.2
2	Region 24MB By Extended Memory (2.4MB×5)	0.204sec (S810/10) 0.0689sec (S820/80)	2.9
3	Region 108MB By Extended Memory (10.8MB×5)	0.148sec (S810/10) 0.0290sec (S820/80)	5.1

Table 2 Variation of CPU Time by use of Extended Memory