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SDDI 기법을 이용하는 개구를 가지는 평행평판 구조의 전자파 간섭 해석

Analysis of Electromagnetic Interference of a Parallel Plate with Apertures using the SDDI Technique

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요 약

본 논문에서는 SDDI 기법을 모멘트 법에 적용하여 개구를 가지는 평행평판 구조에 대한 전자파 간섭 문제를 해석하였다. 특히 이 문제에 대하여 SDDI 기법의 응용범위가 무한급수형 그린함수의 계산으로 확장된다. 이 방법은 모멘트 법의 적용 시, 전체 계산시간을 줄이면서 수치 해석적 효율성을 개선한다. 제안된 방법의 유효성을 입증하기 위해 개구상의 전계 분포를 얻어 참고문헌의 결과와 비교하였다. 이 방법에 의한 수치해석 결과는 다른 것과 잘 일치함을 보였다.

Abstract

In this paper, the electromagnetic interference of a parallel plate with apertures is characterized by the method of moment(MoM), using the Spline-type Divided-Difference Interpolation(SDDI) technique. Particularly, for the solution of the problem, the application of the SDDI technique is extended to the calculation of the summation-type Green's functions. It improves numerical efficiency, having accuracy and saving the overall computational time required in the MoM application. For validating the proposed method, the electric fields on the apertures are calculated and compared to those of the literature. The numerical results show good agreement with them.

I. Introduction

As the operating frequency of a system increases, the mechanism of electromagnetic coupling and interference can be more complex to consider. To prevent the unexpected failures in operation from occurring, ahead of design and fabrication, the electromagnetic interference should be robustly predicted.

It is quite often issued that electromagnetic energy is spuriously coupled between the external space and the inside of an aircraft through apertures. It is important to obtain how to analyze the electromagnetic interference of this case such as using a parallel plate with apertures[1]~[4].

The method of moment is used as a numerical method to predict the electromagnetic phenomena. In applying the method to the parallel plate case, the summation-type Green's function is essential to the mixed potential integral equation. To calculate

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multiple integrals including the Green's function requires an enormous amount of time. For improving numerical efficiency, the SDDI technique[5],[6] is extended from complex-variable integration to summation.

In this paper, for the verification of the validity of the proposed method, the electromagnetic coupling into the parallel plate through apertures is investigated. The numerical results are in good agreement with those of the related literature.

II. Theory

In high frequencies, the electromagnetic coupling into the parallel plate through an aperture can be modeled as shown in Fig. 1. The electromagnetic field from the external space is incident on an aperture, the thickness of which is zero. Through the aperture, the energy is coupled to the inside of the parallel plate. To solve this problem, it is necessary to satisfy the boundary conditions on the aperture.

$$\overline{H}^{s,-} + \overline{H}^{i,-} + \overline{H}^{r,-} = \overline{H}^{s,+} \tag{1}$$

Superscripts $\pm$ correspond to $z=0^{\pm}$. i, r and s mean incidence, reflection and scattering, respectively. The incident magnetic field is given as

$$\overline{H}^{i,} = \widehat{k^i} \times \hat{a} \frac{e^{-j\overline{k}^i \cdot \overline{r}}}{\eta} \tag{2}$$

where $k=\sqrt{\varepsilon_0\mu_0}$, $\eta=\sqrt{\frac{\mu_0}{\varepsilon_0}}$, $\overline{k}^i = k_x^i\hat{x} + k_y^i\hat{y}+k_z^i\hat{z}$, $\widehat{k^i}=\frac{\overline{k}^i}{k}$, $\overline{r}=x\hat{x}+y\hat{y}+z\hat{z}$.

$\hat{a}$ is the polarization vector of incidence, and $e^{j\omega t}$ is the time-dependence and suppressed. The scattered magnetic fields inside and outside the parallel plate are

$$\overline{H}^{s,\pm} = -j\frac{k_{\pm}}{\eta_{\pm}} \overline{F}^{\pm}(\overline{r}) - \nabla\phi_m(\overline{r}) \tag{3}$$

where $k_+=\sqrt{\varepsilon_r}k$, $k_-=k$, $\eta_+=\frac{\eta}{\sqrt{\varepsilon_r}}$, $\eta_-=\eta$, $\overline{F}^{\pm}(\overline{r})=\int \overline{\overline{g}}^{\pm}_{m'n'}(\overline{r},\overline{r}')\cdot\overline{M}^{\pm}_s(\overline{r}')d\overline{r}'$. ϕ_m and $\overline{F}^{\pm}(\overline{r})$ the magnetic scalar and electric vector potentials, respectively. $\overline{\overline{g}}^{\pm}_{m'n'}(\overline{r},\overline{r}')$ is the dyadic Green's function, and m' and n' stand for the directions of the vector potential and magnetic point source. $\overline{\overline{g}}^{-}_{m'n'}(\overline{r},\overline{r}')$ is the free space dyadic Green's function, and $\overline{\overline{g}}^{+}_{m'n'}(\overline{r},\overline{r}')$ is represented as

$$\overline{\overline{g}}^{+}_{m'n'}(\overline{r},\overline{r}') = \widehat{m'}\widehat{n'} \sum_{n=-\infty}^{\infty} \cdot \frac{e^{-jk_+\sqrt{(x-x')^2+(y-y')^2+(z-z'+2nW)^2}}}{4\pi\sqrt{(x-x')^2+(y-y')^2+(z-z'+2nW)^2}} \tag{4}$$

where W is the separation of the parallel plate. Equation (4) can be evaluated by the SDDI scheme[5],[6]

In the MoM frame work, equation (3) is discretized by the basis expansion and testing and the resulting matrix equation is routinely solved.

III. Numerical results

The geometry shown in Figure 1 is under consideration.

Regions $(+)(z>0)$ and $(-)(z<0)$ are filled with

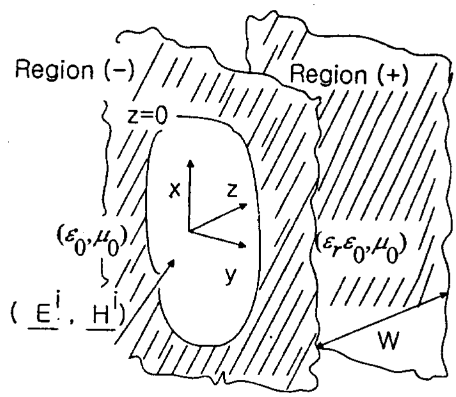


그림 1. 개구가 있는 평행평판

Fig. 1. A parallel plate with an aperture.

the materials of $(\varepsilon_r\varepsilon_0, \mu_0)$ and (ε_0, μ_0), respectively. The relative permittivity $\varepsilon_r = 1$, and the y-polarized electric field is normally incident on the aperture.

Firstly, equation (4) is calculated by the conventional and proposed techniques, and compared to $\overline{\overline{g}}_{m'n'}(\overline{r}, \overline{r}')$ in Figure 2. The truncation number of the summation is set as 300. A 5-ordered interpolating function is used in the SDDI scheme.

In Figure 2, the values obtained by the SDDI technique(◆) agree very well with those of the summation(-●-).

Secondly, the scattered electric field on the $0.5\lambda \times 0.5\lambda$ rectangular aperture with $W=2.8\lambda$ is considered. To evaluate the magnetic current on it, 9 rooftop basis functions are used in each of x and y directions. Figures 3(a)-(c) show the computed distribution of the field along x and y directions, compared to the data in [1].

The values obtained by the SDDI technique(-) accurately approach those in [1](●). On the surface of the aperture, as the y-component of the electric field is proportional to the x-directed magnetic field it shows the edge behavior in the y-direction. The computational times required by the SDDI technique and the summation are com-

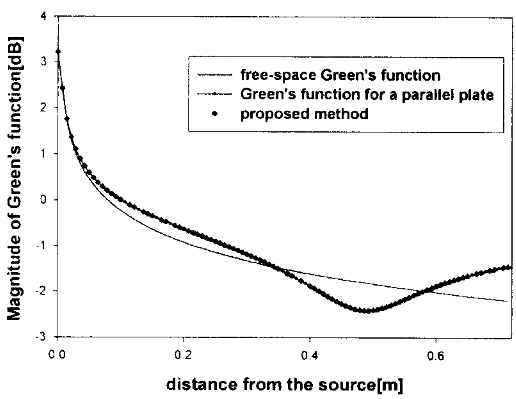
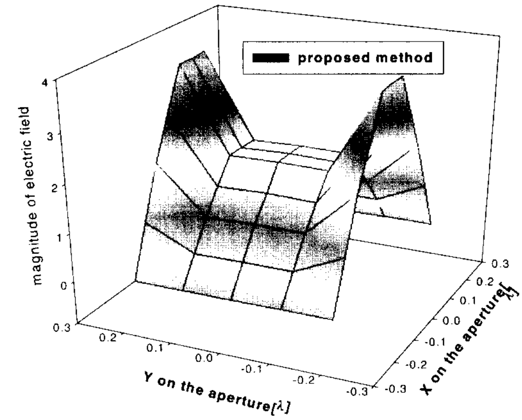


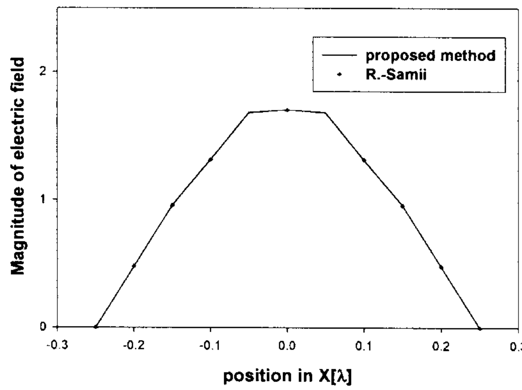
그림 2. 그린함수의 비교

Fig. 2. Comparison of Green's functions.



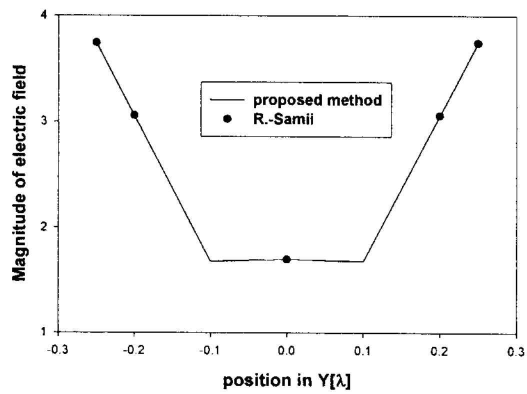
(a) 3차원 분포

(a) 3-D view



(b) R.-Samii의 결과와 비교

(b) compared with R.-Samii's(X-directed cut)



(c) R.-Samii의 결과와 비교(Y방향 단면)

(c) compared with R.-Samii's(Y-directed cut)

그림 3. 개구상의 전계 분포

Fig. 3. Electric-field magnitude on the aperture.

표 1. 무한급수와 제안된 기법에 의한 계산시간의 비교
Table 1. Computational times required by the summation and the proposed method.

	Summation	Proposed method
Computational time	1.487×10^{3} sec	0.762×10^{3} sec

pared in Table 1.

The time saving of about 49 % can be achieved by the proposed technique over the direct integration of the summation-type Green's function like equation (4).

Thirdly, the effect of the plate separation W on the aperture electric field is observed at(0.5 λ, 0.05 λ, 0) as in [1]. 1 $\lambda\times$0.1 λ is the aperture size. To find the electric field on it, 19 rooftop basis functions are used in x and 1 in y directions. The values obtained in this manner are compared to those of the summation in Figure 4.

Figure 4 shows good agreement between the calculated result by the SDDI technique(-) and the data in [1](●). To a degree, the two groups of data cannot perfectly agree, for the numbers of the basis functions used in this study are even smaller than those in [1]. The validity of the SDDI scheme can be proved by a physical and self-consistent interpretation of Figure 4 that when W reaches the resonant separation mentioned in [1] (corresponding to the dips in Figure 4) the energy is captured mostly inside the parallel plate and the electric field on the interface gets reduced.

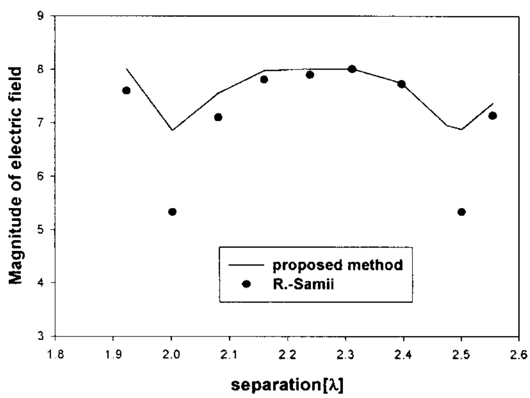


그림 4. 평행평판 분리폭 변화에 대한 개구상 전계의 크기(R.-Samii의 결과와 비교)
Fig. 4. Electric-field magnitude on the aperture with varied W(compared with R.-Samii's).

Ⅳ. Conclusion

The Spline-type Divided-Difference Interpolation (SDDI) technique is extended to the calculation of the summation-type Green's function, which is indispensable to the integral equation for analyzing the electromagnetic coupling into the parallel plate through apertures. This approach can save the overall computational time and is found to be useful in predicting the electromagnetic interference occurring in this geometry.

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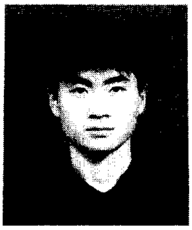

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