# Electromagnetic Scattering and Absorption of Conducting Elliptic Cylinder Coated with Lossy Ferrite Absorber 

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## 1. Introduction

Recently, electromagnetic interference in a computer system have become a big problem in mobile communication. Therefore we have to cover or shield against an unwanted radio wave. We consider a general shape with electric wave absorption by ferrite, a shield effect in order to prevent unnecessary scattering of an electromagnetic wave as such as in electromagnetic compatibility problem. Because of the complexity of these models, the analysis of scattering using them becomes very difficult. We considered an infinite conducting elliptic cylinder as a simple model. This model described by elliptic cylinder is replaced by general shape. Propagation and scattering of electromagnetic waves in the presence of objects with elliptic geometry have many interesting features. In this paper, the analysis model consists of an infinite conducting elliptic cylinder coated with lossy ferrite absorber. We obtained numerical results for this model using FD-TD method. We considered that incident wave is assumed to be a plane wave. We analyzed the effect of a ferrite film by FDTD method and evaluated the shield effect of undesirable scattering. We showed that we could prevent undesirable scattering by coating a ferrite film to an obstacle.

## 2. Analysis of scattering by FD-TD method

The analysis model is shown in fig.1. The parameters of the conducting elliptic cylinder are length of the major axis a1 and the length of minor axis bi. Similarly, the parameters of the conducting elliptic cylinder coated with lossy ferrite absorber are the length of the major axis $\mathrm{a}_{2}$ and the length of minor axis $\mathrm{b}_{2}$. And the parameters of ferrite are dielectric constant $\varepsilon=\varepsilon_{1}-j \varepsilon_{2}$ and permeability $\mu=\mu_{1}-j \mu_{2}$. The incident wave is a plane electromagnetic wave of wavelength $\lambda$ at an angle of incidence $\alpha$. The incident wave is given by equivalence sources J . These sources are located on lines $l_{1}$ and $l_{2}$, and are represented by the following equations.

$$
\begin{align*}
& \mathbf{J}=\mathbf{n} \times \mathbf{H}  \tag{1}\\
& \mathbf{H}=-\sqrt{\frac{\varepsilon}{\mu}}\left(E_{z}^{i} \cos \alpha \mathbf{i}_{x}+E_{z}^{i} \sin \alpha \mathbf{i}_{y}\right)  \tag{2}\\
& \mathbf{E}=E_{z}^{i} \mathbf{i}_{z}  \tag{3}\\
& E_{z}^{i}=E_{0} \cos (\omega t-k x \cos \alpha+k y \sin \alpha) \tag{4}
\end{align*}
$$

Where n indicates for the normal vector to the boundary and k is wave number.
The FD-TD method is formulated by discretization of Maxwell equations,


$$
\begin{align*}
& H_{x}^{n+\frac{1}{2}}\left(i, j+\frac{1}{2}\right)=C_{0} H_{x}^{n-\frac{1}{2}}\left(i, j+\frac{1}{2}\right)-C_{1}\left\{E_{z}^{n}(i, j+1)-E_{z}^{n}(i, j)\right\}  \tag{5}\\
& H_{y}^{n+\frac{1}{2}}\left(i+\frac{1}{2}, j\right)=C_{0} H_{y}^{n-\frac{1}{2}}\left(i+\frac{1}{2}, j\right)+C_{1}\left\{E_{z}^{n}(i+1, j)-E_{z}^{n}(i, j)\right\} \tag{6}
\end{align*}
$$

$$
E_{z}^{n}(i, j)=C_{2} E_{z}^{n-1}(i, j)-C_{3} J^{n-\frac{1}{2}}(i, j)
$$

$$
\begin{equation*}
+C_{4}\left\{H_{x}^{n-\frac{1}{2}}\left(i, j+\frac{1}{2}\right)-H_{x}^{n-\frac{1}{2}}\left(i, j-\frac{1}{2}\right)-H_{y}^{n-\frac{1}{2}}\left(i+\frac{1}{2}, j\right)+H_{y}^{n-\frac{1}{2}}\left(i+\frac{1}{2}, j\right)\right\} \tag{7}
\end{equation*}
$$

Where,

$$
\begin{array}{ll}
C_{0}=\frac{1-\Delta t \mu_{2} / 2 \mu_{1}}{1+\Delta t \mu_{2} / 2 \mu_{1}} & C_{1}=\frac{\Delta t / \mu_{1} \Delta s}{1+\Delta t \mu_{2} / 2 \mu_{1}} \\
C_{2}=\frac{1-\Delta t \sigma / 2 \varepsilon_{1}}{1+\Delta t \sigma / 2 \varepsilon_{1}} & C_{3}=\frac{\Delta t / \varepsilon_{1}}{1+\Delta t \sigma / 2 \varepsilon_{1}}
\end{array} \quad C_{4}=\frac{\Delta t / \Delta s \varepsilon_{1}}{1+\Delta t \sigma / 2 \varepsilon_{1}}
$$

$\mathrm{i}, \mathrm{j}$ indicate the position in $\mathrm{x}-\mathrm{y}$ plane, and n is number of time steps. $\Delta s=\Delta x=\Delta y$ is space increment, and $\Delta t$ is time increment. For stability of the FD-TD solution, $\Delta s$ and $\Delta t$ should satisfy the condition, $\quad \Delta t \leq \Delta s / \sqrt{2} c$. c is propagation velocity in the free space.

By using these equations, propagation of electromagnetic wave in an infinite analysis region is modeled, but since infinite computer memory is not possible, appropriate boundary conditions of the second order must be applied.

## 3. Numerical results

The results of the numerical calculations on the near fields by the elliptic cylinder having different parameters are presented in this section. We carried out calculations using parameters $f=10 \mathrm{GHz}, \lambda=0.03 \mathrm{~m}, \Delta t=0.002 \mathrm{~ns}$ and $\Delta s=0.001 \mathrm{~m}$ and other frequencies such as $f=1$ and 5 GHz . In fig. 1 analysis region is divided into $\mathrm{N}_{\mathrm{i}}=300$ and $\mathrm{N}_{\mathrm{j}}=300$ grid points. Equivalence sources J are located on line $\mathrm{l}_{1}(\mathrm{i}=1)$ and $\mathrm{l}_{2}(\mathrm{j}=268)$.

Figure 2 shows the near field patterns of circular cylinder model in case of $f=10 \mathrm{GHz}$. In the parameters of fig.2, the length of the major axes are $\mathrm{a}_{1}=\mathrm{b}_{1}=5 \mathrm{~cm}\left(\mathrm{a}_{1} / \lambda=\mathrm{b}_{1} / \lambda=1.6\right)$ and $\mathrm{a}_{2}=\mathrm{b}_{2}=6 \mathrm{~cm}\left(\mathrm{a}_{2} / \lambda=\mathrm{b}_{2} / \lambda=2\right)$. Therefore, thickness of ferrite is $\mathrm{d}=1 \mathrm{~cm}(\mathrm{~d} / \lambda=0.33)$. The angle of incidence is $\alpha=45$ degrees, and the dielectric constant and permeability of the ferrite absorber are $\varepsilon=15.6$ and $\mu=0.5-j 0.2$, respectively.


Fig. 2 Near electric field of circular cylinder model (the case of $\alpha=45$ degrees)

(a) the case of conducting elliptic cylinder

(b) the case of conducting elliptic cylinder coated with absorber

Fig. 3 Near electric field of elliptic cylinder model 1 (the case of $\alpha=45$ degrees)

(a) the case of conducting elliptic cylinder

(b) the case of conducting elliptic cylinder coated with absorber

Fig. 4 Near electric field of elliptic cylinder model 2 (the case of $\alpha=45$ degrees)
The intensities are indicated as total electric field amplitudes. In these figures the weak amplitudes are shown by gray regions and the strong amplitudes are shown by white and black regions.

Figure 2(a) shows the case of conducting circular cylinder, and fig.2(b) shows the case of conducting circular cylinder coated with ferrite absorber. The scattered intensities of the case of circular cylinder coated with ferrite are weak compared to

(a) the case of conducting elliptic cylinder

(b) the case of conducting elliptic cylinder coated with absorber

Fig. 5 Near electric field of elliptic cylinder model 2 (the case of $\alpha=90$ degrees)
the case of conducting circular cylinder. The absorption effect of ferrite absorber is given.
Figure 3 shows the near field patterns of elliptic cylinder model 1 for $f=10 \mathrm{GHz}$. In the parameters of fig. 3 , the length of the major axes are $a_{1}=5 \mathrm{~cm}\left(a_{1} / \lambda=1.6\right)$ and $\mathrm{b}_{1}=3 \mathrm{~cm}\left(\mathrm{~b}_{1} / \lambda=1.0\right)$, and the length of the minor axes are $\mathrm{a}_{2}=6 \mathrm{~cm}\left(\mathrm{a}_{2} / \lambda=2.0\right)$ and $\mathrm{b}_{2}=4 \mathrm{~cm}\left(\mathrm{~b}_{2} / \lambda=1.3\right)$. Thickness of ferrite is $\mathrm{d}=1 \mathrm{~cm}(\mathrm{~d} / \lambda=0.33)$. The angle of incidence, dielectric constant and permeability are the same as that fig.2. Similarly, the scattered intensities of the case of elliptic cylinder coated with ferrite are weak compared to the case of conducting elliptic cylinder. But, the absorption effect of ferrite absorber is smaller than the case of circular cylinder.

Figure 4 and 5 shows the near field patterns of elliptic cylinder model 2 for $f=10 \mathrm{GHz}$. The parameters of model2 are $\mathrm{a}_{1}=5 \mathrm{~cm}\left(\mathrm{a}_{1} / \lambda=1.6\right), \mathrm{b}_{1}=0.5 \mathrm{~cm}\left(\mathrm{~b}_{1} / \lambda=0.16\right)$, $\mathrm{a}_{2}=6 \mathrm{~cm}\left(\mathrm{a}_{2} / \lambda=2.0\right)$ and $\mathrm{b}_{2}=1.5 \mathrm{~cm}\left(\mathrm{~b}_{2} / \lambda=0.5\right)$. The angle of incidence are $\alpha=45$ degrees and 90 degrees, respectively. The dielectric constant and permeability are the same as that fig.2. The scattered intensities of the case of $\alpha=90$ degrees are weak compared to the case of $\alpha=45$ degrees. When we mounted with ferrite, we damp more than -30 dB in the ferrite inside and understand that an absorption effect is provided. Absorption effects of other frequencies such as $f=1$ and 5 GHz are also evaluated.

## 4. Conclusion

The phenomenon of scattering from an infinitely long conducting circular and elliptic cylinder coated with lossy ferrite absorber is considered. We obtained the numerical solution using the FD-TD Method. Numerical results were shown for near fields when $\alpha=45,90$ degrees. In future, we plan to conduct numerical simulations by considering various other parameters for mobile communication and a comparison of the present results with our earlier exact solutions for the present model.

## References

[1] T. Masuda and Y. Miyazaki, Trans. IEE Japan, vol.118-C, No.1, pp.112-117 (1998)
[2] Y. Miyazaki and T. Masuda, Proc. of 1998 China-Japan Joint Meeting on Microwaves, Beijing, pp.235-238 (1998)
[3] T. Masuda and Y. Miyazaki, Technical report of IEICE EMCJ2001-99, pp67-72 (2001)
[4] K. Hatakeyama, Z. Chi, K. Yamauchi and T. Tsutaoka, Proc. of 2000 China Japan Joint Meeting on Microwave, pp.238-241 (2000)
[5] H. Komori and Y. Konishi, IEEE Trans. Broadcasting, vol.40, No.4, pp.219-222 (1994)

