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A consideration on error of Poynting vector estimation with near-magnetic-field measurement

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1. Introduction

Progress of clock frequency of digital equipments causes serious undesired emission from a printed-circuit board(PCB). Since a trial-and-error at later procedure spends cost and time, design criterion for low-emission PCB is desired. To establish the design criterion, it is necessary to understand mechanism of emission. For this purpose, many investigations on near-field measurement for estimating current distribution, predicting far-field pattern, and improving measurement accuracy are reported. However, some index denoting propagation of emission is required because near-electric or magnetic-field pattern do not always state a mechanism of propagation for undesired emission.

We have proposed a method to estimate the Poynting vector from near-magnetic-field measurement [1]. Since the Poynting vector indicates direction of propagation for electromagnetic wave, it is useful to understand a mechanism of emission. We have confirmed that the proposed method has capability to visualize energy flow experimentally [2]. However, an estimation error was not discussed in the previous work.

In this report, we discuss on error of the proposed method. We measured magnetic-field generated from a transmission line to estimate the Poynting vector. The obtained value is compared to the theoretical value, which is calculated analytically by using vector potential.

2. Estimation method of the Poynting vector

We describe the proposed method of the Poynting vector estimation.

It is necessary to obtain both electric(E)- and magnetic(H)-fields for calculation of the Poynting vector. However, measurement of both E- and H-fields makes an equipment complicated. In the proposed method, E-field is estimated from measured H-field using the Maxwell's equation. To apply the Maxwell's equation, derivative operation for the measured H-field is required. In the proposed method, the Yee scheme [3] is employed to execute derivative operation for the discretely obtained H-field. Yee scheme arranges E- and H-fields on the Yee cell shown in Fig. 1. By obtaining magnetic-field values on the Yee cell from measurement, electric-field and the Poynting vector are estimated by computation. Since the proposed method is based on Maxwell's equation in phasor expression, both strength and phase measurement is required. Usually, probes are scanned mechanically above the *x*-*y* plane. To use proposed method, magnetic-field is measured in three layers shown in Fig. 2 in order to calculate z-direction derivative.

Maxwell's equation in a source-free space in phasor expression

$$\nabla \times \mathbf{H} = j\omega\varepsilon_0 \mathbf{E} \qquad (1)$$

yields

$$\mathbf{E} = \frac{1}{j\omega\varepsilon_0} \nabla \times \mathbf{H}. \qquad (2)$$

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Therefore, the near-electric-field distribution is calculated from the measured near-magnetic fields. Discrete components on the Yee cell are

$$E_x(i,j,k) = \frac{1}{j\omega\varepsilon_0}\left\{\frac{H_y(i,j,k+1)-H_y(i,j,k)}{\Delta z}-\frac{H_z(i,j+1,k)-H_z(i,j,k)}{\Delta y}\right\} \quad (3)$$

$$E_y(i,j,k) = \frac{1}{j\omega\varepsilon_0}\left\{\frac{H_z(i+1,j,k)-H_z(i,j,k)}{\Delta x}-\frac{H_x(i,j,k+1)-H_x(i,j,k)}{\Delta z}\right\} \quad (4)$$

$$E_z(i,j,k) = \frac{1}{j\omega\varepsilon_0}\left\{\frac{H_x(i,j+1,k)-H_x(i,j,k)}{\Delta y}-\frac{H_y(i+1,j,k)-H_y(i,j,k)}{\Delta x}\right\}, \quad (5)$$

where the index $\frac{1}{2}$ is omitted.

The complex Poynting vector $\mathbf{S}$ [W/m^2], whose direction shows the direction of energy flow, and whose magnitude shows the propagating energy density, is defined as

$$\mathbf{S} = \frac{1}{2}\mathbf{E}\times\mathbf{H}^\star, \quad (6)$$

where asterisk denotes a complex conjugate. Discrete components of the Poynting vector [4] is calculated as

$$S_x(i,j,k) = \frac{1}{2}\left\{E_y(i,j,k)\cdot H_z^\star(i,j,k) - H_y^\star(i,j,k)\cdot E_z(i,j,k)\right\} \quad (7)$$

$$S_y(i,j,k) = \frac{1}{2}\left\{E_z(i,j,k)\cdot H_x^\star(i,j,k) - H_z^\star(i,j,k)\cdot E_x(i,j,k)\right\} \quad (8)$$

$$S_z(i,j,k) = \frac{1}{2}\left\{E_x(i,j,k)\cdot H_y^\star(i,j,k) - H_x^\star(i,j,k)\cdot E_y(i,j,k)\right\}. \quad (9)$$

When the measured H-field includes measurement error, estimated E-field and Poynting vector will be influenced.

3. Experiment

We made a transmission line with risers (Fig. 3) as a measurement model. The transmission line and the risers were made of 2.1mm-diameter brass lines. The characteristic impedance of the transmission line was 50 Ω. The ground plane was made of 3mm-thick aluminum plate. One terminal of the transmission line was excited by a network analyzer at 3GHz. Another terminal was terminated with a 50 Ω load.

We fabricated three probes to measure H_x, H_y, and H_z on the Yee cell shown in Fig. 4. The probes were shielded-loop type ones fabricated from semirigid cable. The probes were scanned on the measurement line along the x axis shown in Fig. 3. Three heights of measurement line were 11.05mm, 15.55mm, and 14.05mm above the ground plane. The size of the Yee cell was $\Delta x = \Delta y = \Delta z = 3$ mm.

In order to verify the estimation of the E-field, the probe head has E_z probe also, which is small monopole antenna fabricated from semirigid cable.

4. Consideration

The strength of the measured H-field is shown in Fig.5 with dotted line. The strength of the estimated E-field and the Poynting vector are shown in Fig.6-7 with solid line. The theoretical values are shown with broken line, which are calculated analytically by using vector potential, assuming the TEM mode.

We can see in Fig.5 that the measurement error of H-field is within 3dB when the theoretical strength is larger than -10 dB. However, when the theoretical strength is small, the measurement error become large although they are stronger than noise level. It is suggested that the undesired sensitivity for E-field of H-field probe, and direction discrimination are dominant when the H-field is small.

The estimated E-field strength has noise-like error while the measured H-field strength does not have it. Since the estimation is based on phasor expression Maxwell's equation, the phase measurement error of H-field affects on the strength of the E-field estimation.

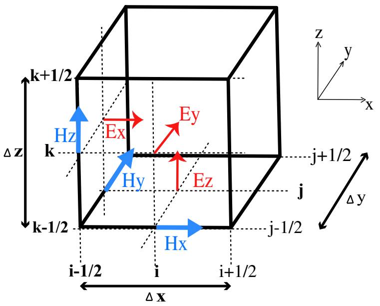


Figure 1: Electric and magnetic fileds on the Yee cell

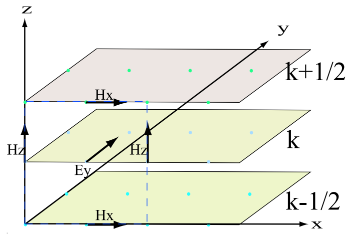


Figure 2: Measurement plane

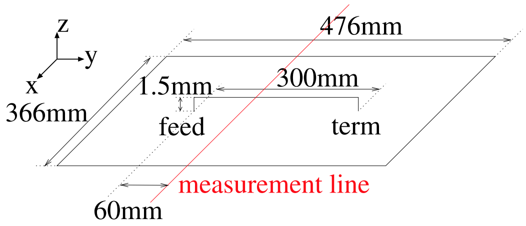


Figure 3: Transmission line on ground plane

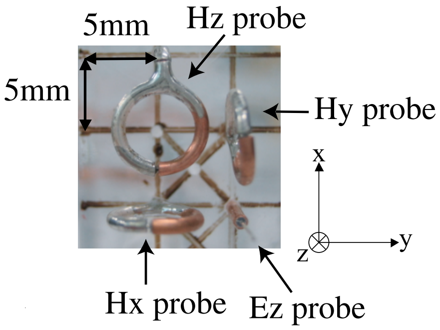


Figure 4: Fablicated probes

The error of the y component of the Poynting vector is up to 5dB while the x and z components show larger error. The Poynting vector should direct y-direction dominantly because the current propagates along the y axis. It is thought that the less direction discrimination and sensitivity for E-field of the H-field probe affects the accuracy of non-dominant components of the Poynting vector.

5. Conclusion

We have measured the Poynting vector distribution generated from a transmission line to discuss measurement error. We have found that the proposed method has high accuracy for estimating the Poynting vector of dominant direction. However, estimation of non-dominant direction is less accuracy because of incompleteness of the H-field probe.

To propose a calibration method to compensate incompleteness of the probe for the Poynting vector measurement is further study.

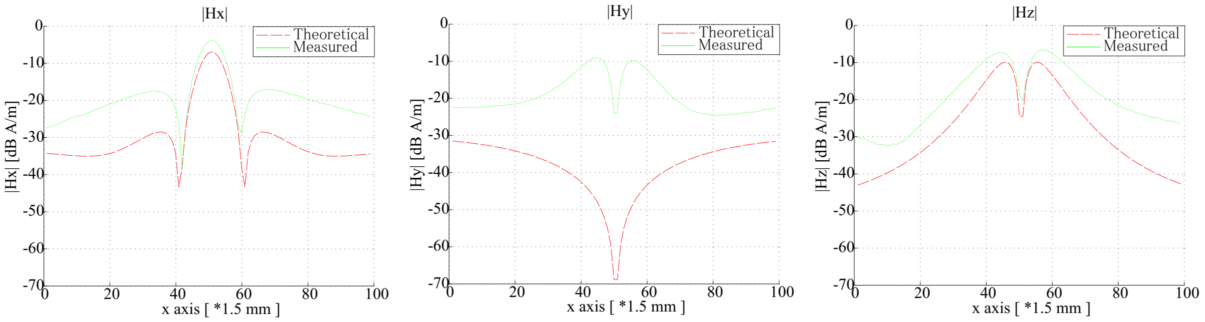
References

[1] Hiroshi Hirayama, Yoshio Kami, “Near-field Measurement using Yee Scheme for Precision Evaluation and Poynting Vector Acquisition,” Proc. of EMC Zurich, pp. 661-666, Feb. 2003

[2] Hiroshi Hirayama, Hidekazu Hayashi, Nobuyoshi Kikuma, Kunio Sakakibara, “Estimation of Poynting Vector and Wavemumber Vector From Near-Magnetic-Field Measurement,” Proc. of Antem/URSI 2006, pp. 89-92, July. 2006

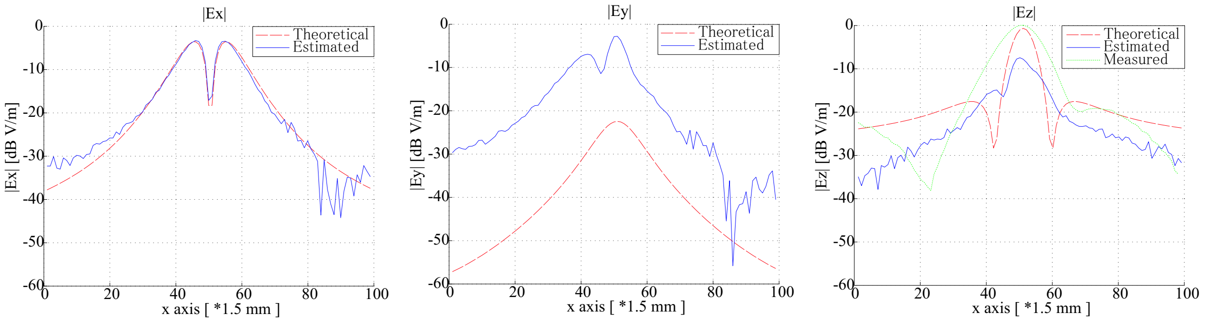
[3] K.S.Yee, “Numerical solution of initial boundary value problem involving Maxwell’s equations in isotropic media,” IEEE Trans. on Antennas and Propagation, AP-14, no.3, pp.302-307, 1966.

[4] Allen Taflove, Computational Electrodynamics: the finite-difference time-domain method, Artech House, 1995.



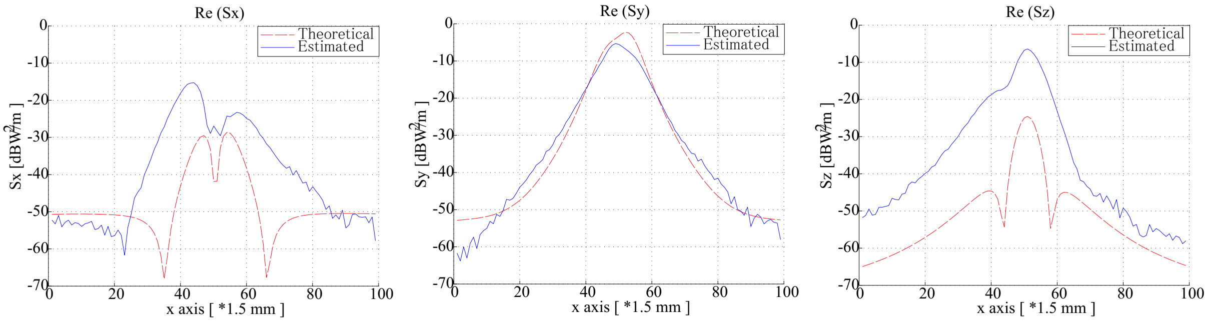
H_x H_y H_z

Figure 5: The magnetic fields



E_x E_y E_z

Figure 6: The electric fields



S_x S_y S_z

Figure 7: The poynting vector