A Method of Estimating the Intra-EMC Problem Using the Weighted Magnetic Field Correlation Considering Noise Source Polarization

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***Abstract*—A novel design method has been developed to solve the Intra-EMC problem in mobile equipment. Recently, there has been a great deal of interest in the deterioration of receiver sensitivity due to the leakage of noise into a receiver circuit via the antenna. To solve this problem, we developed a design method in our previous studies that could estimate the optimal layout of a noise source according to the correlation between the magnetic distributions of the antenna and the noise source. However, the changes in the polarization of the noise source were not sufficiently taken into consideration in previous studies. In this paper, we have proposed a new design method to estimate the optimal layout of a noise source using the weighted magnetic field correlation while also considering the noise source polarization. The effectiveness of the proposed method, which uses a TEG to simulate a portable telephone, has been verified. We confirmed a good correlation between the coupling characteristics (S21) and the weighted magnetic field correlation has been achieved even if the polarization of the antenna and that of the noise source are different.**

I. INTRODUCTION

Recently, noise generated from digital circuits in portable equipment has leaked into the receiver circuit, thus deteriorating receiver sensitivity. In particular, since downsizing has resulted in placing the antenna of wireless communication equipment ever closer to the noise source, a significant amount of noise is delivered via the propagation channel created between the communication antenna and the noise source. However, there is no effective solution, making it necessary to develop a new design method to solve the coupling problem by developing an antenna that takes into account its own characteristics. Moreover, the antenna characteristics often greatly changes depending on the structure of phone, making it necessary to design an antenna that minimizes the influence of noise in the early stages of development to the extent possible.

In our previous studies, we proposed a design method to estimate the optimal layout of noise sources that can be calculated according to the correlation between the magnetic distribution of the noise source and that of the antenna, and we demonstrated the effectiveness of this proposed design method [1]-[2]. On the other hand, the conventional method calculates the correlation coefficient using the magnitude of the magnetic distribution of the noise source and that of the antenna. Therefore, it is not sufficient to consider the polarization of the noise source. That is, since the antenna that performs wireless communications has a certain polarization characteristic, it is expected that the electromagnetic coupling between an antenna and a noise source changes significantly. It has been shown, because an evaluation based only on the magnitude of each magnetic field of an antenna and a noise source is incomplete, it is necessary to develop a design method that takes polarization into consideration.

In this paper, in order to solve the disadvantages of the conventional method, we propose a novel design method to estimate the optimal layout of a noise source using the weighted magnetic field correlation while considering noise source polarization. We have evaluated the proposed method using a test element group (TEG) that simulates a portable telephone.

II. A CONCEPT OF CORRELATION OF MAGNETIC FIELD

A digital circuit is modelled as an antenna that acts as the source of the radiation noise. In general, a digital circuit is composed of an IC as the signal source, an IC as the load, and lines connecting the two ICs. In operating the IC, the signal current flows in the wire and the return current flows in the ground plane: therefore, we modelled the noise source as a loop antenna. The Intra-EMC problem can be regarded as the result of electromagnetic coupling between two antennas.

Usually, electromagnetic coupling between two antennas can be easily measured as a coupling characteristic (S21) by connecting each of the two ports to a network analyser, since a feeding port is present in the antenna [3]. However, it is difficult to take measurements between the noise source and the antenna because the noise source has no specified feeding port. This prompted us to investigate whether the overlap between two near-field magnetic distributions could act as an index for assessing the Intra-EMC problem. We treat this correlation coefficient as a new index for quantifying the overlap between two near-field magnetic distributions [1]-[2].

In general, radiation noise arises from the signal current. On the other hand, many studies have used the currents as a method to estimate the radiation noise [4]-[6]. Therefore, we focus on the magnetic field that occurs from the currents as a solution to the Intra-EMC problem.

III. A NEW INDEX CONSIDERING NOISE SOURCE POLARIZATION

Our novel design method was developed by using the weighted magnetic field correlation while considering the noise source polarization. Here, we define a polarization as the direction of the magnetic field. That is, since a magnetic field occurs in the direction perpendicular to the conductor in which current flows, polarization serves as a direction that intersects perpendicularly with the conductor. The weighted magnetic field correlation is given by

$$\gamma_w = \frac{n_x^2}{n_x^2+n_y^2+n_z^2}\gamma_x + \frac{n_y^2}{n_x^2+n_y^2+n_z^2}\gamma_y + \frac{n_z^2}{n_x^2+n_y^2+n_z^2}\gamma_z \tag{1}$$

In Eq. (1), the correlation coefficient (γ_x, γ_y, γ_z) of each polarization is calculated by using Eq. (2a), Eq. (2b), and Eq. (2c) and it is weighted by the sum of squares of amplitude for each noise source polarization shown by Eq. (3a), Eq. (3b), and Eq. (3c).

$$\gamma_x = \frac{\sum_{i=1}^{n}\left(|H_{axi}|-|\overline{H}_{ax}|\right)\left(|H_{nxi}|-|\overline{H}_{nx}|\right)}{\sqrt{\sum_{i=1}^{n}\left(|H_{axi}|-|\overline{H}_{ax}|\right)^2}\sqrt{\sum_{i=1}^{n}\left(|H_{nxi}|-|\overline{H}_{nx}|\right)^2}} \tag{2a}$$

$$\gamma_y = \frac{\sum_{i=1}^{n}\left(|H_{ayi}|-|\overline{H}_{ay}|\right)\left(|H_{nyi}|-|\overline{H}_{ny}|\right)}{\sqrt{\sum_{i=1}^{n}\left(|H_{ayi}|-|\overline{H}_{ay}|\right)^2}\sqrt{\sum_{i=1}^{n}\left(|H_{nyi}|-|\overline{H}_{ny}|\right)^2}} \tag{2b}$$

$$\gamma_z = \frac{\sum_{i=1}^{n}\left(|H_{azi}|-|\overline{H}_{az}|\right)\left(|H_{nzi}|-|\overline{H}_{nz}|\right)}{\sqrt{\sum_{i=1}^{n}\left(|H_{azi}|-|\overline{H}_{az}|\right)^2}\sqrt{\sum_{i=1}^{n}\left(|H_{nzi}|-|\overline{H}_{nz}|\right)^2}} \tag{2c}$$

$$n_x^2 = \frac{1}{N}\sum_{i=1}^{N}|H_{nxi}|^2 \tag{3a}$$

$$n_y^2 = \frac{1}{N}\sum_{i=1}^{N}|H_{nyi}|^2 \tag{3b}$$

$$n_z^2 = \frac{1}{N}\sum_{i=1}^{N}|H_{nzi}|^2 \tag{3c}$$

where γ_x is the correlation coefficient of x-component, γ_y is that of y-component, and γ_z is that of z-component shown from Eq. (2a) to Eq. (2c). In addition, n_x^2, n_y^2 and n_z^2 are the average power of the noise source. Here, we explain H_{axi} and H_{nxi}. In Eq. (2a), "a" or "n" of the first subscript means the magnetic field of the antenna and that of the noise source, "x" of the second subscript means the x-component of the magnetic field of the antenna or that of the noise source, and "i" of the third script means the observation point (i). Similarly, Eq. (2b) is the equation for the y-component and Eq. (2c) is that for the z-component. Therefore, since the weighted magnetic field correlation γ_w is the index that is weighted by the average power of the noise source of each polarization, it can take into consideration the influence of a dominant polarization of the magnetic field.

On the other hand, in Eq. (4), γ is the correlation coefficient by using the conventional method [1]-[2]. In Fig. (4), γ is calculated by using Eq. (5a) and Eq. (5b) where H_{ai} in Eq. (5a) is the sum of squares calculated by the amplitude of the magnetic field of the antenna for each component and H_{ni} in Eq. (5b) is the sum of squares calculated by the amplitude of the magnetic field of the noise for each component. However, sufficient consideration cannot be given to changes in the polarization of the noise source by using the square sum of amplitude. Hence, when the polarization of the antenna and that of the noise source are different, the conventional coefficient cannot adequately serve as an evaluation index.

$$\gamma = \frac{\sum_{i=1}^{n}\left(|H_{ai}|-|\overline{H}_{ai}|\right)\left(|H_{ni}|-|\overline{H}_{ni}|\right)}{\sqrt{\sum_{i=1}^{n}\left(|H_{ai}|-|\overline{H}_{ai}|\right)^2}\sqrt{\sum_{i=1}^{n}\left(|H_{ni}|-|\overline{H}_{ni}|\right)^2}} \tag{4}$$

$$H_{ai} = \sqrt{|H_{axi}|^2+|H_{ayi}|^2+|H_{azi}|^2} \tag{5a}$$

$$H_{ni} = \sqrt{|H_{nxi}|^2+|H_{nyi}|^2+|H_{nzi}|^2} \tag{5b}$$

Therefore, we propose a new design approach to estimate the optimal layout of a noise source by using the weighted magnetic field correlation while also considering the noise source polarization.

IV. EVALUATION USING A TEG SIMULATING A PORTABLE TELEPHONE

A. *Outline of an Evaluation Model*

Figure 1 shows the evaluation model we used to evaluate the proposed design approach, which uses an electromagnetic field analysis simulator (MW-STUDIO) for calculation.

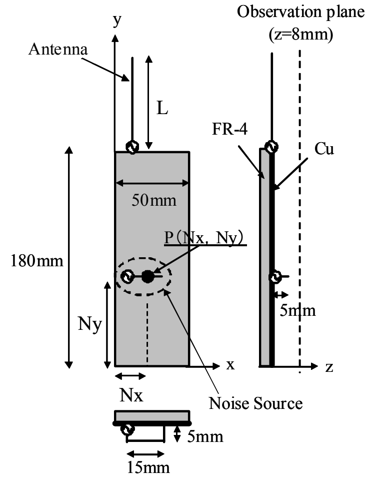


Fig. 1. Evaluation model

In Fig. 1, the substrate size of the evaluation model that emulates a portable telephone is 50mm wide and 180mm long, and the monopole antenna is connected to the upper part of the substrate. The loop antenna that models the noise source is 25mm in length and 5mm in height, and it is set on the substrate. For calculation at 900MHz, the typical frequency used by portable telephones, the length L of the antenna is assumed to be L=83mm (1/4 wavelength). As shown in Fig. 1, the evaluation model horizontally arranges the noise source in a direction perpendicular to the monopole antenna. In this evaluation, the center of the loop antenna (P (N_x, N_y)), which acts as the noise source is evaluated as the variable parameter.

B. Evaluation Results

Figure 2 shows the correlation coefficient at N_x=20mm calculated from the two magnetic distributions while changing the location of the noise source (N_y). In Fig. 2, ▲ is γ (conventional method), ■ is γ_w (proposed method), ● is γ_x (H_x), ◆ is γ_y (H_y) and × is γ_z (H_z). When the polarization of the antenna and that of the noise source differs, we assume that γ_w and γ_y have the same behaviour but γ and γ_y have different behaviours. Therefore, we can assume that the weighted magnetic field correlation γ_w reflects the tendency of the noise source polarization.

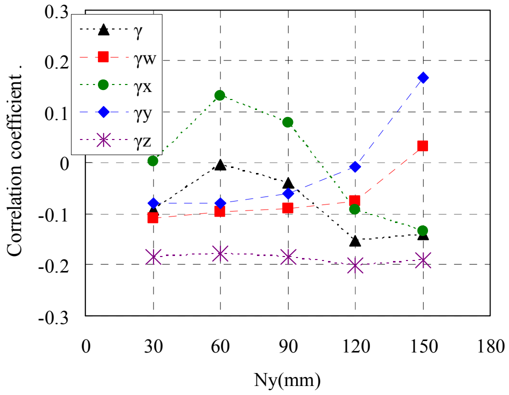


Fig. 2. Correlation coefficient

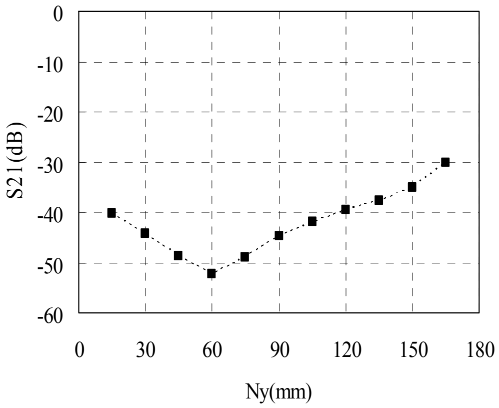


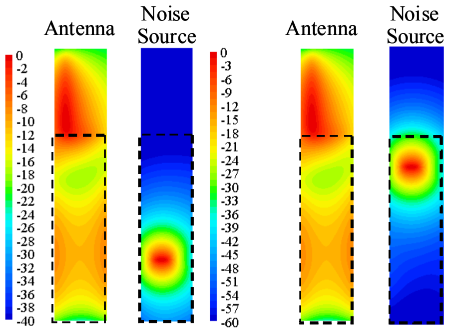
Fig. 3. Coupling characteristic (S21)

Figure 3 shows the coupling characteristic (S21) at N_x =20mm while changing the location of the noise source (N_y). A comparison of Fig. 2 and Fig. 3 shows a strong tendency for coupling characteristic (S21) and γ_w but a weak tendency for coupling characteristic (S21) and γ corresponding to the position of the noise source. Therefore, this confirms that a good agreement between the coupling characteristic (S21) and the weighted magnetic field correlation is achieved when the polarization of the antenna and that of the noise source are different.

Next, we explain the reason for the above results by using the magnetic distributions. Figure 4 shows the change in magnetic distribution for two examples with different noise source positions. The figure shows the magnetic distributions corresponding to the conventional method. Fig. 4(a) shows an example when the coupling characteristic (S21) is small and Fig. 4(b) shows an example when it is large. The dashed line is the outline of the substrate, and the magnetic distribution of the antenna is concentrated near the antenna element and the center area of the substrate. The obtained results are interpreted as follows. The length of the substrate is equivalent to about a half wavelength of the evaluation frequency, and the current distribution is the smallest at the edge of the substrate and the largest at the center of the substrate. In Fig. 4(a), the coupling characteristic (S21) is small (S21=−52.3dB), although the noise source is located in the center of the substrate where the magnetic distribution of the antenna is most concentrated. On the other hand, in Fig. 4(b), the coupling characteristic (S21) is large (S21=−35.1dB), although the noise source is located where the magnetic distribution of the antenna is extremely small. Therefore, when the polarization of the antenna and that of the noise source are different, the intensity level of electromagnetic coupling and the degree of overlap between the two fields show the opposite tendencies. This indicates that an evaluation based only on the amplitude of each magnetic field of the antenna and the noise source is insufficient.

Now we apply the new design method when the polarization of the antenna and that of the noise source are different. Since the proposed method is based on the correlation coefficient weighted by the average power of the noise source of each polarization, we evaluate the average power of the noise source. As shown in Fig. 2, the behaviours of γ_x and γ are in agreement, but the behaviours of γ_x and the coupling characteristics are not in agreement. Furthermore, the relationship between n_x^2 and n_y^2 is $n_y^2 \gg n_x^2$ ($n_y^2 \fallingdotseq 9^* n_x^2$), and the weighted magnetic distribution coefficient (γ_w) decrease the influence of γ_x. On the other hand, the relationship between n_x^2 and n_y^2 is $n_y^2 \gg n_x^2$, γ_y strongly reflects the calculated results of γ_w as a main factor. Hence, the weighting by the average power of the noise source acts as a “switch” to selectively extract the dominant polarization of the noise source.

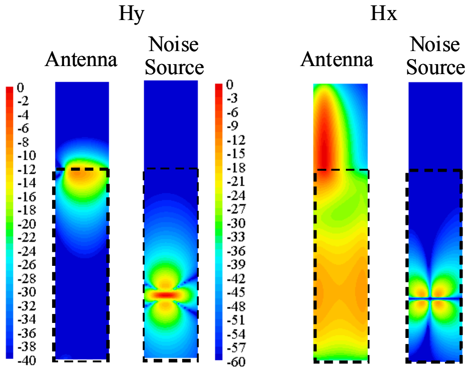
Furthermore, we explain the above effect by using the magnetic distribution. Figure 5 shows the change in magnetic distribution for two examples with different positions of the noise source. Figure 5(a) shows an example when the coupling characteristic (S21) is small and Fig. 5(b) shows an example when it is large. In addition, the left side of Fig. 5(a) and Fig. 5(b) shows the magnetic distribution (H_y), while the right side shows the magnetic distribution (H_x). In the right-hand side of Fig. 5(a), since the noise source is located where the magnetic distribution of the antenna is strong, γ_x is large. In the left-hand side of Fig. 5(a), since the noise source is located where the magnetic distribution of the antenna is weak, γ_y is small. On the contrary, in the right-hand side of Fig. 5(b), since the noise source is located where the magnetic distribution of the antenna is weak, γ_x is small. In the left-hand side of Fig. 5(b), since the noise source is located where the magnetic distribution of the antenna is strong, γ_y is large. As described above, we focus attention on H_x. If the location of the strength of the magnetic field of the antenna and that of the noise source is corresponding, the correlation is large regardless of the strength of the magnetic field of the noise source. However, since the average power of H_x is smaller than that of H_y, we need to remove the influence on the average power of H_x. As shown in Eq. (2), to remove the influence of the noise source on H_x, the weighting plays a role in considering the influence on the noise source polarization. That is to say, by using the weighted magnetic field distribution while considering the noise source polarization, it is clearly that it is possible to estimate the optimal positioning of a noise source quantitatively.



Nx=20mm, Ny=60mm Nx=20mm, Ny=150mm

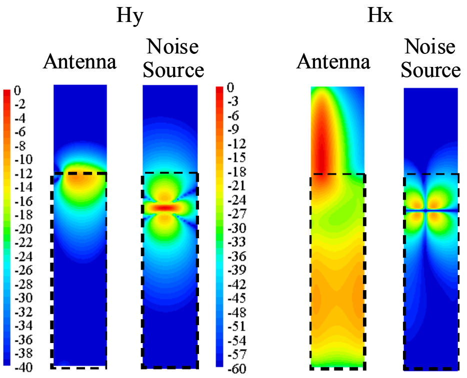
(a) For a small coupling (b) For a large coupling

Fig. 4. Magnetic distribution (conventional method)



Nx=20mm, Ny=60mm

(a) For a small coupling



Nx=20mm, Ny=150mm

(b) For a large coupling

Fig. 5. Magnetic distribution (proposed method)

V. CONCLUSION

We have developed a novel design method that can estimate the optimal layout of the noise source while considering the noise polarization. The effectiveness of the proposed method was assessed using a TEG simulating a portable telephone. Consequently, good agreement was confirmed between the weighted magnetic field correlation and coupling characteristics (S21) while changing the location of the source, even if the polarization of the antenna and that of the noise source were different. Further studies are needed to extend the design method with ability to handle quantitative evaluation, since the weighted magnetic field correlation is a relative index.

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