

A Method for Optimal Layout of Noise Sources Using the Correlation between the Magnetic Distribution of Antenna and Noise Source

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Abstract—We have developed a novel design method in response to the “intra-EMC problem.” In portable equipment, noise generated from digital circuits in the equipment leaks into the receiver circuit, causing a deterioration in receiver sensitivity. In particular, since downsizing has resulted in the antennas within wireless communication equipment becoming ever closer to the noise source, a significant amount of noise is delivered via the propagation channel that is created between the communication antenna and the noise source. In developing our novel design method, we have modeled the noise source and antenna from the phenomena generated in equipment. We have discovered that the optimal layout of noise sources can be calculated according to the correlation between the magnetic distribution of the noise source and that of the antenna.

Key words: intra-EMC problem, magnetic distribution, correlation coefficient, coupling characteristic (S21)

I. INTRODUCTION

An increasing number of intra-EMC problems have emerged with the increasing promotion of new integrated functions, such as 1 seg-based digital TV, GPS, camera and Bluetooth, installed in handsets which are being downsized to previously unimaginable dimensions. In portable equipment, noise generated from digital circuits in the equipment leaks into the receiver circuit, causing a deterioration in receiver sensitivity. In particular, since downsizing has resulted in the antennas of wireless communication equipment being placed ever closer to the noise source, a significant amount of noise is delivered via the propagation channel that is created between the communication antenna and the noise source.

In the past, methods of solving the intra-EMC problem have included measuring the slight near-field magnetic distribution of a noise source in the frequency domain or the time domain, estimating the bit error ratio (BER) by adding a modulating signal to the radiation noise near a substrate, and studying the dependency of extraneous radiation noise on the layout of the signal line [1], [2], [3]. However, although the noise generated from a digital circuit leaks into the receiver circuit by propagation via the antenna, any evaluation that takes the antenna characteristics into account cannot solve the problem using the above-mentioned methods. Moreover, the antenna characteristic often greatly changes according to the build of the portable telephone, making it necessary to design

an antenna at the beginning of the development period so as to eliminate the influence of noise as much as possible.

In this study, we have developed a novel design method in response to the intra-EMC problem in consideration of the antenna characteristics. In our development of this novel design method, we have modeled the noise source and antenna from the phenomena generated in the equipment. We have discovered that the optimal layout of noise sources can be calculated according to the correlation between the magnetic distribution of the noise source and that of the antenna. In addition, the validity of the proposed method has been confirmed using a test element group (TEG) designed to model a portable telephone.

II. PROPOSAL OF A NEW INDEX

A. The cause of the problem

In this chapter, we explain the derivation of our novel design method for solving the intra-EMC problem. Fig. 1 shows the layout of the equipment. It is composed of a digital circuit, a RF circuit and a wireless communication antenna connected to the RF circuit. In other words, there are two contributing factors: the radiating noise source and the receiving circuit, in the same piece of equipment. Table 1 shows the two causes of the problem. One is electromagnetic coupling between lines, and the other is antenna-circuit space coupling. In the first case, we can use the EMI Check Tool to solve the problem. However, in the latter case, there is no effective method, making it necessary to develop a new design approach to solving the antenna-circuit space coupling problem that takes into account the characteristics of the antenna.

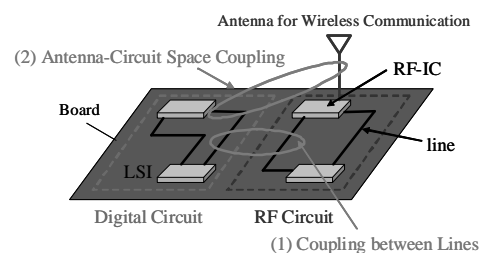


Figure 1 Layout of the equipment

TABLE I
THE CAUSE OF THE PROBLEM

	Problem	Cause	Method of solving the problem
(1)	Coupling between lines	Lines	EMI Check Tool
(2)	Antenna-circuit space coupling	Antenna	No effective method

B. A new approach to the intra-EMC problem

In this section, a digital circuit is first modeled 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 two ICs. On operating the IC, the signal current flows in the wire and the return current flows in the ground plane, so we modeled the noise source as a loop antenna. The intra-EMC problem can thus be regarded as being caused by electromagnetic coupling between two antennas.

Usually, electromagnetic coupling between antennas can be easily measured as S21 by connecting to each port of the Network Analyzer, since a feeding port is present in the antenna [4]. 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 a new index for assessing the intra-EMC problem. Fig. 2 is a schematic view of the magnetic distributions. Table 2 shows the relationship between S21 and overlap of near-field magnetic distribution. When the distance D between the antennas is small, electromagnetic coupling is intensified and the overlap between the two near-field magnetic distributions also increases. Conversely, when distance D is large, the electromagnetic coupling weakens and the overlap also decreases. We therefore attempted to devise a new quantification factor to see how much electromagnetic coupling results by observing the degree of overlap between the two fields. We treat this correlation coefficient as a new index for quantifying the overlap between two near-field magnetic distributions. The correlation coefficient, expressed below as Eq. (1), shows the relationship between the two values. The correlation coefficient is an index that varies between -1 and 1: C = 1 when two parameters (x, y) behave in the same fashion and C = -1 when two parameters (x, y) behave complementary.

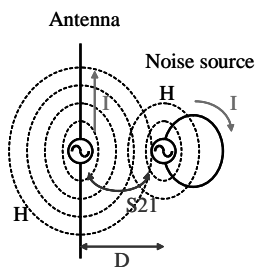


Figure 2 Schematic view of magnetic distributions

$$C = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \cdot \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad (1)$$

(i = 1, 2, …, n)

TABLE II
RELATIONSHIP BETWEEN S21 (COUPLING CHARACTERISTICS) AND OVERLAP OF NEAR-FIELD MAGNETIC DISTRIBUTION

Distance D	Overlap of Near-Field Distributions	S21
Small	Large	Large
Large	Small	Small

C. Example of calculating the correlation coefficient

Figure 3 shows the relationship between the magnetic distribution and the correlation coefficient. Now we consider the four cases shown in Fig. 3, in which various shapes are assumed as magnetic distribution. In Fig. 3, ● shows the place (peak) where the magnetic distribution is strongest, and ○ shows the place (null) where the magnetic distribution is weakest.

In Fig. 3 (a), C = 0.5 because one noise source corresponds to one of the two peaks of the magnetic distribution of the antenna. In Fig. 3 (b), C = -1 because one noise source corresponds to the null of the magnetic distribution of the antenna. On the other hand, in Fig. 3 (c) C = 1 because one noise source corresponds to the peak of the magnetic distribution of the antenna. In Fig. 3 (d), C = -0.5 because one noise source corresponds to one of the two nulls of the magnetic distribution of the antenna.

As understood from Fig. 3, if the number of peaks in the magnetic distribution of the antenna is greater than the number of the peaks of that of the noise source, the correlation coefficient cannot become 1, even if each peak corresponds. Similarly, if the number of the nulls in the magnetic distribution of the antenna is greater than the number of the peaks of that of the noise source, the correlation coefficient cannot become -1. As just described, the possible value of the maximum and minimum changes from -1 to 1 according to the number of the peaks and the nulls of the magnetic distribution of the antenna and noise source.

Hence, it is understood that ideally the correlation coefficient should be small, since the optimal arrangement of the noise source is in the range where the correlation coefficient changes.

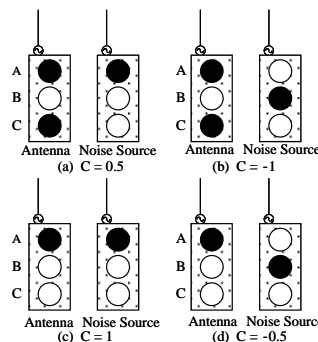


Figure 3 Relationship between Magnetic Distribution and Correlation Coefficient

III. EVALUATION USING A TEG IMITATING A PORTABLE TELEPHONE

A. Outline of an Evaluated Model

Figure 4 shows the evaluation model we used to examine the validity of the proposed design approach, which uses an electromagnetic field analysis simulator (MW-STUDIO) for calculation. In Fig. 4, the substrate size of the evaluation model which emulates a portable telephone is 50 mm wide and 180 mm long; the monopole antenna is connected to the upper part of the substrate, and the loop antenna, 15 mm in length and 5 mm in height, which models the noise source, is set on the substrate. For evaluation at 900 MHz and 2 GHz, the typical frequencies used by portable telephones, the length L of the antenna is assumed to be $L = 83$ mm and $L = 30$ mm ($1/4$ wavelength). In this examination, the center $P(N_x, N_y)$ of the loop antenna that acts as the noise source is evaluated as the variable parameter.

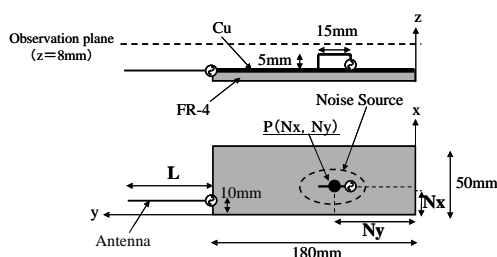


Figure 4 Outline of a Handset Model

B. Evaluated results

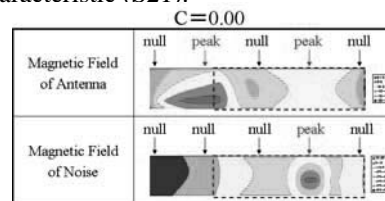
Figure 5 shows the change in magnetic distribution for two examples with different noise source positions at 900 MHz. Fig. 5 (a) shows an example when the correlation coefficient is large, and Fig. 5 (b) shows an example when the correlation coefficient is small. In Fig. 5, the magnetic distribution of the antenna is concentrated near the antenna element and the center part of the substrate. The reason described 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 in the center of the substrate. The correlation coefficient is calculated by substituting the magnetic distribution of antenna and noise source at each position for (x,y) of equation (1) in the range of the substrate and the antenna element on an observation plane 8 mm in height.

In Fig. 5 (a), the correlation coefficient is large and $C = 0$ because a 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. 5 (b), the correlation coefficient is small and $C = -0.18$ because the noise source is located where the magnetic distribution of the antenna is extremely small.

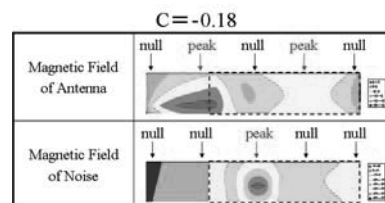
Now we consider the above results using simplified magnetic distributions shown in Fig. 6, in the same manner as described in Fig. 3. Fig. 6 shows the relationship between the magnetic distribution and the correlation coefficient, which just corresponds to the magnetic distributions shown in Fig. 5. In Fig. 5, the magnetic distribution of the antenna has two

peaks and three nulls, and the magnetic distribution of the noise source has one peak and four nulls. Fig. 5 (a) corresponds to Fig. 6 (a), in which one of the peaks among the multiple magnetic distributions of antenna coincides with the peak of the noise source. On the other hand, Fig. 5 (b) corresponds to Fig. 6 (b), in which one of the nulls among the multiple magnetic distributions of the antenna coincides with the peak of the noise source. Therefore, when calculating in a similar manner described in Fig. 3, $C = 0.61$ in Fig. 6 (a) and $C = -0.42$ in Fig. 6 (b). It appears that the difference between the correlation coefficient shown in Fig. 5 and the correlation coefficient shown in Fig. 6 is caused by the fact that the magnetic distribution in Fig. 5 has a complicated shape, whereas the magnetic distribution in Fig. 6 has a simple shape.

Figure 7 shows the coupling characteristic (S_{21}) at 900 MHz between the noise source and antenna while changing the location of the noise source. As shown in Fig. 7, the coupling characteristic (S_{21}) is about 30 dB and changes according to the position of the noise source. Fig. 8 shows the correlation coefficient at 900 MHz calculated from the two magnetic distributions. A comparison of Fig. 7 and Fig. 8 reveals the tendency for S_{21} and the correlation coefficient to closely correspond to the position N_y of the noise source. Also, the locations at which S_{21} and the correlation coefficient are minimized agree with each other. Fig. 9 also shows the coupling characteristic (S_{21}) at 2 GHz between the noise source and antenna while changing the location of the noise source. Fig. 10 shows the correlation coefficient at 2 GHz calculated from the two magnetic distributions. A comparison of Fig. 9 and Fig. 10 shows the strong tendency for S_{21} and the correlation coefficient corresponding to the position N_y of the noise source to correspond closely. Therefore, the locations at which S_{21} and the correlation coefficient are minimized agree with each other. Table 3 shows a comparison between S_{21} and the correlation coefficient. From Table 3, if the correlation coefficient is used, it is clear that it is possible to estimate the optimal positioning of a noise source quantitatively without any knowledge of the coupling characteristic (S_{21}).



(a) For a large correlation coefficient



(b) For a small correlation coefficient

Figure 5 Magnetic Distribution (900 MHz)

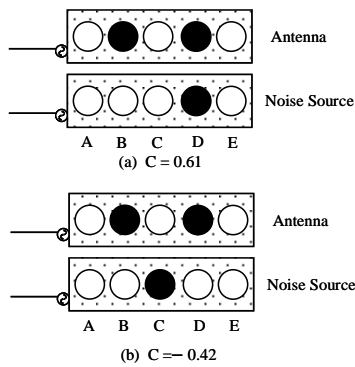


Figure 6 Simplified Magnetic Distributions Corresponding to Fig. 5

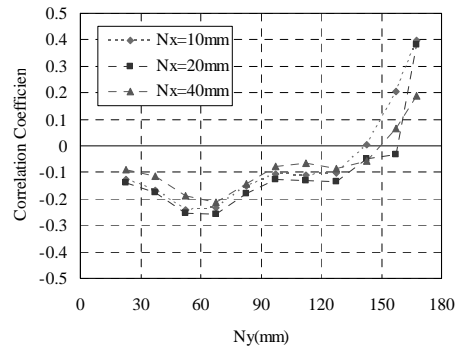


Figure 10 Correlation coefficient at 2GHz

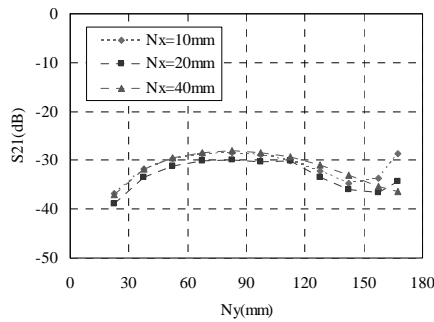


Figure 7 Coupling characteristic (S21) at 900 MHz

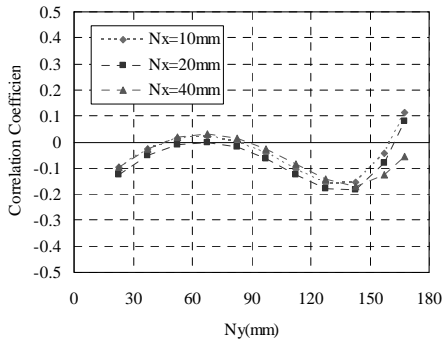


Figure 8 Correlation coefficient at 900 MHz

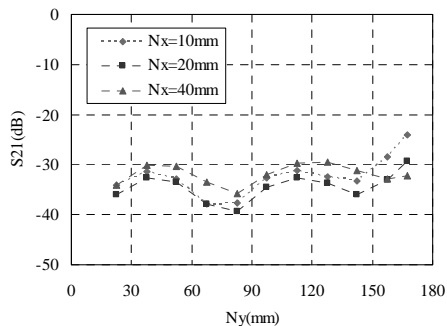


Figure 9 Coupling characteristic (S21) at 2 GHz

TABLE III
COMPARISON BETWEEN S21 AND CORRELATION COEFFICIENT

	S21	Correlation Coefficient	Location of Noise Source
900MHz	-33.4 dB (small)	-0.18 (small)	○
	-30.2 dB (large)	0 (large)	×
2 GHz	-37.8 dB (small)	-0.26 (small)	○
	-33.0 dB (large)	-0.03 (large)	×

IV. CONCLUSION

We have developed a novel design method that can assess the intra-EMC problem by treating it as a two-antenna EM problem. In order to realize an optimal layout of noise sources, our method utilizes the correlation between the magnetic distributions of the noise source and antenna as a new index. Good agreement between the new index (Correlation) and EM-coupling (S21) has been confirmed using a TEG simulating a portable telephone, indicating that the proposed method is a promising candidate for solving the intra-EMC problem. Further studies are needed on the validity of the method using a TEG which includes digital circuits simulating an actual PCB, embedded in a portable telephone and other digital equipment.

REFERENCES

- [1] K. Gotoh, Y. Matsumoto, Y. Yamanaka, and T. Shinozuka, "APD measurement for the disturbance evaluation related to the performance of digital communication systems," IEICE Trans. Commun., vol.E88-B, no.8, pp.3235-3241, Aug. 2005.
- [2] A. Hara, T. Matsumoto, T. Maruyama, H. Yokota, and K. Kashiwagi, "EM interference of intra-ubiquitous equipment," IEICE Technical report, EMCJ2003-5, April 2003.
- [3] H. Sasaki, T. Harada, and T. Kuriyama, "Dependence of signal trace layout on emissions radiated from Printed Circuit Board," IEICE Trans. Commun., vol. J90-B, no.11, pp.1124-1134, Nov. 2007.
- [4] K. Ogawa, and T. Uwano, "Analysis of a diversity antenna comprising a whip antenna and a planar inverted F Antenna for portable telephones," IEICE Trans. Commun., vol. J79-B-2, no.12, pp.1003-1012, Dec. 1996.