Proposal of a new index for predicting communication performance for intra-EMC

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Abstract: We propose a new index for predicting the optimum layout of noise sources, that is designed to improve the communication performance of digital wireless equipment. In our previous studies, we developed a design method for optimizing the layout of a noise source using the correlation between the magnetic field distribution of the noise source and that of the antenna. However, this method does not allow easy comparison between different items of equipment. In this paper, we quantitatively and visually propose a new index that can predict the signal bit error rate by using the antenna interference power, obtained from the weighted magnetic field product that has been calculated from the magnetic field distributions of the noise source and the antenna. We have confirmed that the optimal layout of the noise source can be predicted using our proposal method in digital wireless equipment to minimize intra-EMC. We have further discovered a new index in which the optimal layout of the noise source can be found in contour formatted figures with good visibility.

Keywords: intra-EMC, bit error rate, magnetic distribution, digital wireless equipment

Classification: Electromagnetic Compatibility (EMC)

References

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1 Introduction

The noise generated by digital circuits in digital wireless equipment is increasingly leaking into the receiver circuit, causing a loss of receiver sensitivity. Since down-sizing has resulted in digital wireless equipment antennas being placed ever closer to noise sources, a significant amount of noise is delivered through the propagation channel created between the communication antenna and the noise source. However, there have hitherto been no effective solutions, making it necessary to develop a new design method to solve each individual coupling problem.

In our previous studies, we proposed a design method for estimating the optimal layout of a noise source that can be calculated according to the correlation between the magnetic distribution of the noise source and that of the antenna, and demonstrated the effectiveness of this proposed design method [1, 2]. However, this conventional method cannot be used effectively to compare different layouts and designs, because it is limited to a relative evaluation.

In this paper, we propose a new evaluation index for predicting the optimal layout of noise sources based on signal bit error rate and for minimizing the intra-EMC problem in any item of digital wireless equipment. This is done by quantifying the antenna interference power using a weighted magnetic field product that is calculated from the magnetic field distribution of the noise source and that of the antenna. We have been able to predict the optimal layout of noise sources by evaluating signal bit error rate both quantitatively and visually. We have further discovered that the optimal layout of the noise source can be predicted by using our proposed method in digital wireless equipment for intra-EMC problems.

2 Design process to minimize intra-EMC problems

We can evaluate the communication quality of digital wireless systems by using the carrier-to-noise ratio (CNR). When tackling the intra-EMC problem, in addition to taking into account the noise in the receiver, it should be remembered that the noise generated from digital circuits in digital equipment mixes into the receiving circuit by way of its own antenna. This noise is defined as the antenna interference power P_a . If the noise N in the receiver and the antenna interference power P_a are uncorrelated, the carrier-to-noise ratio (CNR') can be expressed as Eq. (1). The antenna interference power P_a can be expressed using Eq. (2), where P_n is the radiation power of the noise source and S_{21} is the electromagnetic coupling between the antenna and the noise source. In most cases, the electromagnetic coupling can be easily measured as the S-parameter by connecting both ports to a network analyzer, since a feeding port is present in the antenna. However, it is difficult to take measurements between the noise source and the antenna in this case, because the noise source has no specified feeding port. On another front, the radiation noise arises from the signal current. In this paper, we focus on the magnetic field generated by current as a solution to the intra-EMC problem.

$$CNR' = \frac{C}{N + P_a} \quad (1)$$

$$P_a = P_n \cdot S_{21} \quad (2)$$

Based on the considerations mentioned above, we propose the weighted magnetic field product T_w as a new index for estimating the coupling characteristic (S_{21}) between a noise source and an antenna. T_w is a quantitative index that takes the polarization of the noise source into consideration. It is defined in Eq. (3), in which the magnetic field product (T_x, T_y, T_z) of each polarization is calculated using Eq. (4a), Eq. (4b) and Eq. (4c), and is weighted by the sum of squares of amplitude for each noise source polarization shown by Eq. (5a), Eq. (5b) and Eq. (5c). Therefore, since the weighted magnetic field product T_w is an index that is weighted by the average power of the noise source of each polarization, it can take into consideration the influence of the dominant polarization of the noise source.

$$T_w = \frac{n_x^2}{n_x^2 + n_y^2 + n_z^2} T_x + \frac{n_y^2}{n_x^2 + n_y^2 + n_z^2} T_y + \frac{n_z^2}{n_x^2 + n_y^2 + n_z^2} T_z \quad (3)$$

$$T_x = \frac{1}{N} \sum_{i=1}^N (|H_{axi}| \times |H_{nxi}|) \quad (4a)$$

$$T_y = \frac{1}{N} \sum_{i=1}^N (|H_{ayi}| \times |H_{nyi}|) \quad (4b)$$

$$T_z = \frac{1}{N} \sum_{i=1}^N (|H_{azi}| \times |H_{nzi}|) \quad (4c)$$

$$n_x^2 = \frac{1}{N} \sum_{i=1}^N |H_{nxi}|^2 \quad (5a)$$

$$n_y^2 = \frac{1}{N} \sum_{i=1}^N |H_{nyi}|^2 \quad (5b)$$

$$n_z^2 = \frac{1}{N} \sum_{i=1}^N |H_{nzi}|^2 \quad (5c)$$

Next, the electromagnetic coupling S_{21}' (T_w) between an antenna and a noise source is defined as a linear function of T_w as described in Eq. (6) where S_{21}' (T_w) is in units of decibels. K is calculated from S_{21}' (T_w) as shown in Eq. (7). Based on the above, we can calculate the antenna interference power P_a' as denoted by Eq. (8).

Here, we will describe how to determine a and b in Eq. (6). Figs. 1(a) and (b) show the evaluation model we used to evaluate the proposed design approach. It emulates a cellphone 50 mm wide and 180 mm long. The monopole antenna is connected to the upper part of the substrate. The loop antenna that models the noise source is d in length and 5 mm in height. For evaluation at 900 MHz, the length of the antenna is assumed to be 83 mm. In the evaluation model, the noise source is vertically arranged and thus parallel to the monopole antenna shown in Fig. 1(a). We call this the vertical model. In Fig. 1(b), the noise source is horizontally arranged and thus perpendicular to the monopole antenna shown. We call this the horizontal model. In this evaluation, the center position of the loop antenna $P(N_x, N_y)$ is employed as the variable parameter.

Fig. 1(c) shows the relationship between the weighted magnetic field product T_w and the coupling characteristic (S_{21}) while changing the location of the noise

source. In Fig. 1(c), ■ denotes the vertical model when $d = 15$ mm, ▲ denotes the horizontal model when $d = 15$ mm, × denotes the vertical model when $d = 7.5$ mm, and ● denotes the horizontal model when $d = 7.5$ mm in Figs. 1(a) and (b). The broken line is the straight line obtained by linear approximation from both the vertical model and the horizontal model. The results in Fig. 1(c) confirm that the S_{21} is proportional to T_w in the four cases, regardless of the polarization or size of the noise source. As shown in Eq. (6), $S_{21}'(T_w)$ is the value obtained from the linear approximation relationship between T_w and S_{21} using Fig. 1(c). When extracted from Fig. 1(c), a is determined to be 58.3 and b is determined to be -54.3 in Eq. (6). We can thus quantitatively estimate the S_{21} by using the proportional relationship between the two parameters.

$$S_{21}'(T_w) = a \cdot T_w + b \quad (6)$$

$$K = 10^{\frac{S_{21}'(T_w)}{20}} \quad (7)$$

$$P_a' = P_n \cdot K \quad (8)$$

Fig. 1. Relationship between T_w and S_{21} as a function of the size of the noise source

3 Evaluation using a TEG to simulate a cellphone

Fig. 2(a) shows the BER characteristic of the wireless equipment. $\triangle$ denotes the measured results for radio sensitivity, and the broken line indicates the BER characteristics estimated from Eq. (9) using the measured results with no antenna interference power, where γ is CNR and $erfc$ is the complementary error function.

$$P = erfc \sqrt{\frac{\gamma}{2}} \quad (9)$$

The BER characteristics with no antenna interference power in Fig. 2(a) confirm that the CNR is about 10 dB when $BER = 10^{-3}$. Here, to predict the BER degradation in the presence of antenna interference, we try to estimate the BER characteristics from the measured results obtained in this study. In Fig. 2(a), $\square$ denotes the measured results for radio sensitivity when $P_a = -115.5$ dBm. Here, P_n

is -82.5 dBm and the S_{21} is -33.0 dB. The calculations show an approximately 3-dB degradation in the CNR when the antenna interference from the noise source is present at $\text{BER} = 10^{-3}$, as shown in Fig. 2(a). This means that the CNR needs to be increased to be able to equalize the BER characteristics with no antenna interference power. Since T_w was calculated from the two magnetic field distributions to be 0.32, $S_{21}'(T_w)$ is determined to be -35.6 dB due to the proportional relationship between T_w and S_{21} , as shown in Fig. 1(c). The antenna interference power P_a' is therefore found to be -118.1 dBm. We understand that about a 2-dB degradation in the CNR can be predicted using our proposed method when $\text{BER} = 10^{-3}$, as shown in Fig. 2(a). This fact confirms the validity of our proposed method.

Fig. 2(b) shows the BER characteristics of the vertical model while varying the location of the noise source N_y at $N_x = 37.5$ mm. Fig. 2(c) shows them for the horizontal model. It is feasible to estimate the optimal position of a noise source as when the BER curve with antenna interference power is closest to the BER curve with no antenna interference power (Noiseless). From Fig. 2(b) and (c), we can see that $N_y = 15$ mm is the most suitable position for the vertical model, whereas for the horizontal model, any location except for $N_y = 165$ mm is a suitable position. We conclude from the above investigations that the prediction of the optimal layout is feasible using the proposed method, without any knowledge of the coupling characteristics (S_{21}).

Fig. 2. BER characteristics

4 A proposal for communication quality achievement rate

We propose the communication quality achievement rate α as a new index for quantitatively determining the optimal positioning of the noise source. α is defined as the ratio of the area S' that meets the predetermined signal bit error rate for the area S of the entire substrate as shown in Eq. (10), when the CNR is given. For example, Fig. 3 shows the change in the distribution of signal bit error rate when the CNR is set to 10 dB. Fig. 3(a) depicts the vertical model and Fig. 3(b) depicts the horizontal model.

$$\alpha = \frac{S'}{S} \times 100 \quad [\%] \quad (10)$$

In the vertical model shown in Fig. 3(a), we found that the distribution of the signal bit error rate is concentrated near the antenna element and the center part of the substrate. On the other hand, in the horizontal model as shown in Fig. 3(b), we found that the distribution of signal bit error rate is the broadest at the upper part of the substrate. Moreover, if we define a range in which signal bit error rate is 5×10^{-3} or less for S' in Eq. (10), the α of the vertical model is about 10% or less, since α for the horizontal model is about 95%. This indicates that there is greater design freedom when the noise source is horizontally arranged than when it is vertically arranged. This allows us to use α to quantitatively judge the optimal layout of the noise source.

Fig. 3. Distribution of the bit error rate

5 Conclusion

We have proposed a new index that can be used to judge the optimal layout of a noise source based on the evaluation of the BER characteristics using the weighted magnetic field product. The effectiveness of the proposed method was assessed using a TEG to simulate a cellphone. We confirmed that our proposed method can be employed to estimate the signal bit error rate. It is clear that we can successfully predict the optimal layout of noise sources in digital wireless equipment so as to minimize intra-EMC problems.