Study of Electromagnetic Noise Coupling in Wireless-LAN Communication System

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***Abstract*— This paper shows experimental results of packet error rates (PERs) in wireless-LAN mounted printed circuit boards and gives a discussion on a mechanism of electromagnetic noise coupling that affects the PER. We utilized the amplitude probability distribution (APD) to investigate the noise coupling channel. We measured magnetic near-field distribution to obtain information about a noise source. Based on measurement results, we also performed a parallel plate resonance analysis to find out an electromagnetic interference (EMI) antenna. Evaluation results indicate that noise radiates from a board edge and its coupling to an antenna causes an increase of the PER.**

Key words: packet error rate, noise coupling, amplitude probability distribution, magnetic near-field measurement, resonance analysis.

I. Introduction

The electromagnetic interference (EMI) problems inside wireless communication equipment such as a handy phone and a note-type PC become more serious with the increase of the operational speed and packaging density of electronic devices. Especially, the degradation of the communication performance due to coupling of noise arising from a digital circuit to an analog/RF circuit is an important issue. To meet this problem, it is needed to find out the noise source and its coupling channel and to understand the mechanism of the performance degradation.

One solution to understand noise properties is to characterize test circuits. Conventional measurement apparatuses such as a network analyzer and a spectrum analyzer can be a powerful tool for noise coupling analysis [1][2]. Also, applying an electromagnetic near-field probe is considered to be a very effective way of investigating an EMI source [3][4].

More recently, the amplitude probability distribution (APD), which is a statistical method for noise evaluation, is paid much attention as an effective tool for evaluation of EMI inside wireless communication equipment [5][6]. It has been reported that there is a strong correlation between the APD and bit error rate (BER). Moreover, obtaining a two-dimensional APD map of the circuits one can suppose the source of noise that affects BER.

The purpose of this study is to understand a coupling path of noise that affects the wireless communication performance to make a good design. In this paper, we report on evaluation results of a wireless-LAN mounted printed circuit board (PCB). We show measurement results of packet error rate (PER). To visualize noise coupling, APD was measured using an antenna for wireless-LAN. Furthermore, we investigated an EMI antenna by means of both near-field measurement and resonance analysis.

II. Test board

We fabricated a test PCB that contains RF and media access control/base band (MAC/BB) circuits, which are elements of a wireless-LAN circuit block, and a field programmable gate array (FPGA) circuit as a noise source.

Figure 1 shows a picture of the board. Its dimension is 31cm x 21cm. An antenna is connected to the board (near the RF circuit) through the SMA connector. The operation mode of the FPGA circuit is controlled by switches on the board shown in Figure 1.

Figure 2 is a schematic of a cross section of the board. It comprises six conductive layers, each of which is separated by a glass epoxy resin (FR-4). Signal traces are formed on its top and bottom surfaces.

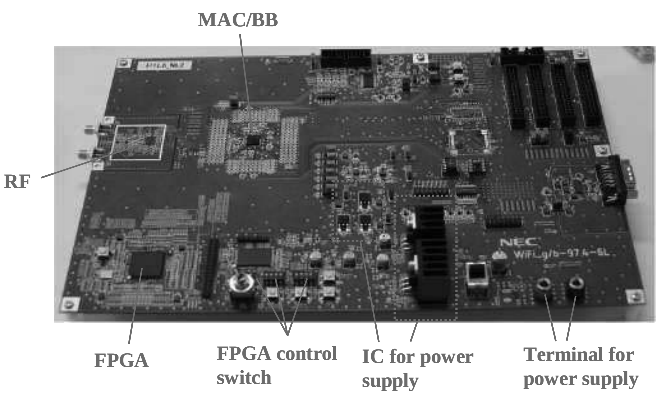


Fig. 1 Picture of a test board.

III. Measurement results of PER

Figure 3 shows a PER measurement system. A receiving board was located inside an anechoic chamber and intensity of a signal sent from a transmitting board was adjusted by attenuators when PER measurement was performed. The circuit operation was controlled by a PC. We measured PER at 2.4 GHz band by two ways of communication. One was by

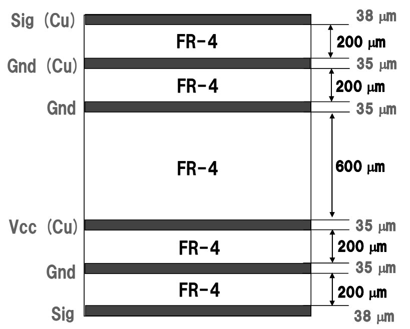


Fig. 2 Cross section of a board.

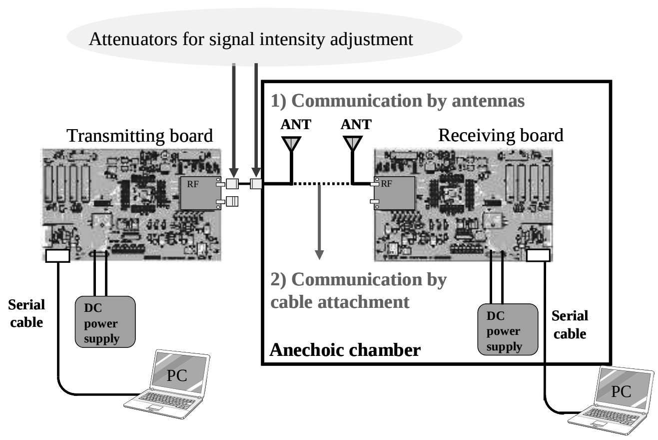
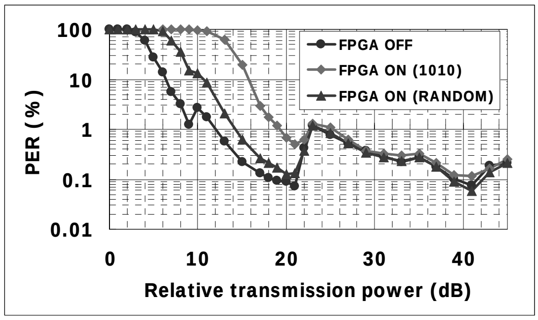
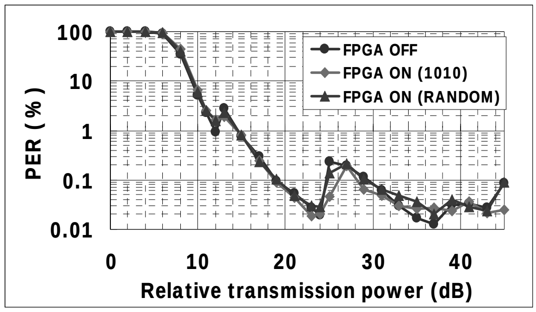


Fig. 3 PER measurement system.



(a)



(b)

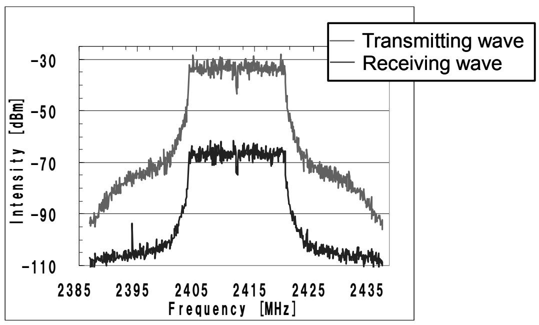
Fig. 4 Measured results of PER. In cases of antenna linking (a) and cable attachment (b).

antenna linking and the other cable attachment as shown in Figure 3.

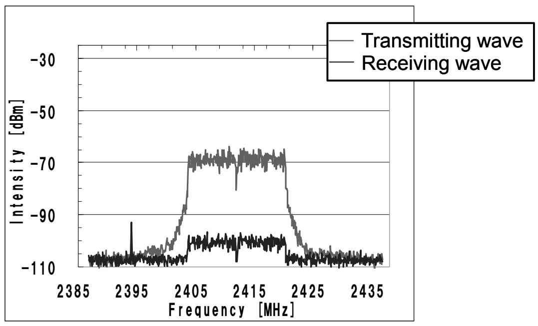
Measured results of the PER are shown in Figure 4 where (a) is the case of antenna linking and (b) demonstrates cable attachment. The measurements were performed for both on and off cases of the FPGA operation with basic frequency of 133 MHz. We selected two kinds of the operation mode, one is random and the other is periodic (1010). It is obvious that the PER increases by the FPGA on only for antenna linking. This suggests the degradation of the PER is caused by the noise coupling to an antenna through the space.

Figure 5 shows the frequency spectra of transmitting and receiving waves with different transmission powers presented in Figure 4(a). Figures 5(a) and 5(b) are those with the relative transmission powers of 45 dB and 10 dB, respectively. From this result, we can consider that the PER increase with the FPGA on occurs when the level of the receiving wave is near the noise level of the spectrum.

As shown in Figure 4(a), the PER for the periodic FPGA mode is larger than that for the random mode in the power range below 20 dB. To investigate this reason, we measured magnetic near-field intensity over the FPGA package utilizing a loop type probe [7]. The result is shown in Figure 6. Strong peaks were observed when the periodic mode was selected



(a)



(b)

Fig. 5 Frequency spectra of transmitting and receiving waves with different transmission powers in Fig. 4 (a). Relative transmission powers are 45 dB (a) and 10 dB (b).

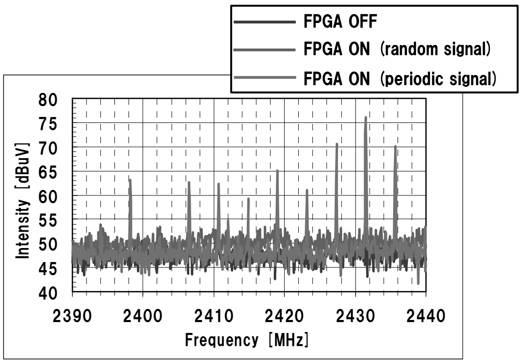


Fig. 6 Results of magnetic field measurements.

while there was no peak in case of the random mode. This result suggests that noise level is higher in case of the periodic mode, which causes larger PER.

IV. Measurement results of APD

To investigate the validity of the coupling channel of noise described above, we measured the APD using only the receiving board. The APD is defined as the percentage of time for which a disturbance intensity exceeds a threshold level [5]. These concept and details are described in Ref. 5 as a statistical method for electromagnetic disturbance evaluation.

Figure 7 shows the APD measurement system. We measured the APD using an antenna for wireless-LAN. The antenna was detached from the board and connected to a spectrum analyzer through a coaxial cable at almost the same position as the original one. The APD measurement apparatus we used was made by Anritsu Corporation and can measure simultaneously five kinds of APD data (APD data at five frequencies with 1 MHz interval).

The measured results at 2.4 GHz band are shown in Figure 8 where the data for both cases of the FPGA operation on and off are plotted. Figures 8(a) and 8(b) include the cases for random operation mode and periodic mode, respectively. It is clearly observed that the APD curves shift to the high amplitude side by the FPGA on. Also, the shift is larger for the case of the periodic mode. We should mention that when the antenna was not connected to the cable (only the cable was located on the board) the APD curves did not shift. This is considered to be the result of noise coupling to the antenna through the space. Also, this result verifies that the PER degradation is caused by the noise coupling to the antenna.

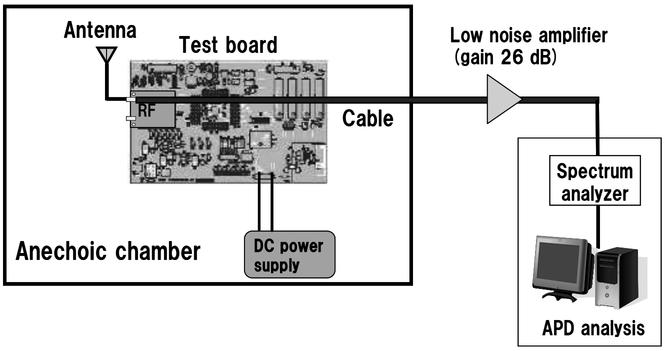
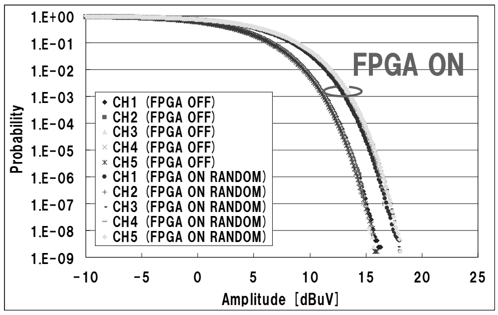
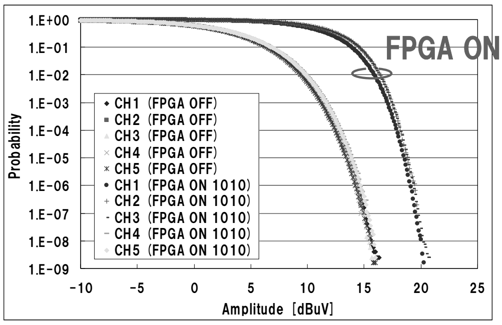


Fig. 7 APD measurement system.



(a)



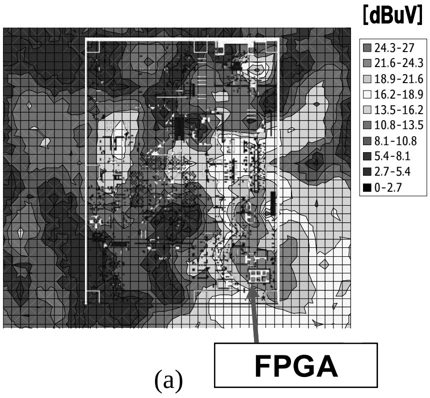
(b)

Fig. 8 Measured results of APD with and without FPGA operation (random mode (a) and periodic mode (b)). CH1: 2.430 GHz; CH2: 2.431 GHz; CH3: 2.432 GHz; CH4: 2.433 GHz; CH5: 2.434 GHz.

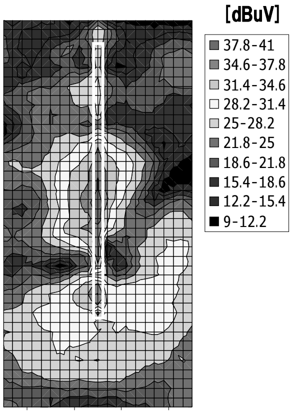
V. Investigation of radiation source

We have investigated an unintended radiation source, namely an EMI antenna. First, we measured magnetic near-field distributions over the board. Figure 9(a) represents the near-field map over the surface of the board. FPGA with periodic mode was active. One can observe strong magnetic field at the edge of the board near the FPGA. In addition, we tried to obtain a field map along the board edge. For this purpose, the probe was scanned over the edge of the board. Figure 9(b) shows the mapping result in which it seems that a standing wave along the edge generates.

To verify this consideration, we performed SPICE based resonance analysis [8]. Analysis object was power-ground planes (4^{th} and 5^{th} layers in Fig. 2) connected to the FPGA. It is noted that the power plane exists near the board edge in the



(a)



(b)

Fig. 9 Magnetic near-field maps over the board surface (a) and the board edge (b). White contour within images indicates the outline of the board. Measurement frequency was 2.444 GHz.

shape of a line. We simulated voltage distribution of parallel plates with the shape of the power plane at 2.4 GHz. The simulation result is shown in Figure 10. Note that the board layout is also shown for understanding the location of the power plane. It is clearly seen that a standing wave along the plane (green is for the high level, blue is for the low level) generates, which means that the power supply system of the FPGA can be the EMI antenna. Although more detailed study is needed, we believe this is a dominant radiation source that degrades PER.

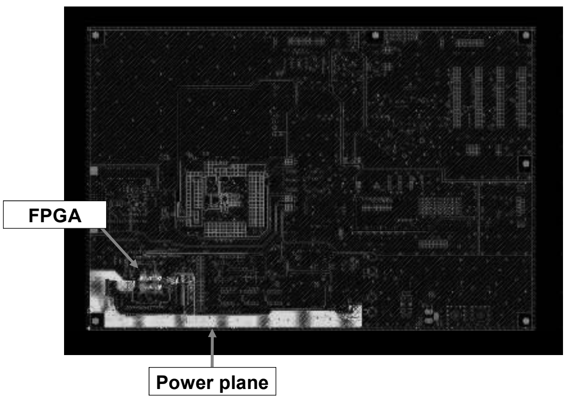


Fig. 10 Simulation result of voltage amplitude distribution on a power plane at 2.4 GHz.

VI. Conclusion

To obtain the information about the mechanism of EMI inside the wireless communication equipment, we fabricated wireless-LAN mounted PCBs and investigated on the noise coupling that affects the PER. We utilized the APD to evaluate a coupling channel of noise. We also investigated an EMI antenna by means of both near-field measurement and resonance analysis.

In this study, it was suggested that noise radiation resulting from the power-ground resonance and its coupling to an antenna caused an increase of the PER.

Acknowledgments

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