Evaluation and analysis of electromagnetic noise coupling in a board with a mixed signal IC

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***Abstract*— In wireless communication terminal such as smart mobile devices, a countermeasure for electromagnetic noise generated by digital circuits becomes more important since it's coupling to an antenna causes degradation of communication performance. To apply an optimum countermeasure, it is very important to find out correctly a noise coupling path. This paper gives evaluation results of noise coupling to an antenna in a test board with a RF and digital mixed IC using the amplitude probability distribution (APD) measurement method. We analytically investigated noise coupling path to an antenna utilizing a correlation coefficient suitable for the APD curve for the test board. Moreover, in order to verify analyzed results the noise coupling path in the test board was evaluated by measurements of In-phase/Quadrature (I/Q) signals.**

Keywords—intra-EMC; noise coupling; APD; Amplitude Probability Distribution; I/Q signal

I. INTRODUCTION

In a wireless communication terminal, electromagnetic noise generated by digital devices is one factor of the decrease of sensitivity. In multiple-input and multiple-output (MIMO) communication system such as mobile telecommunication network compliant with the long term evolution (LTE) standards and wireless local area network (LAN), for expansion of communication capacity, two or more antennas are equipped on a printed circuit board (PCB) and such an intra EMC problem become increasing in an antenna development process. To achieve high antenna performance in the board with many LSIs and antenna components, the identification of LSI acting as a noise source to each antenna is required. A typical method to identify a noise source is probing of the electromagnetic near-field above PCBs and monitoring the peak or average value of noise amplitude. However, the degradation of the communication performance does not depend on only noise amplitude intensity.

The amplitude probability distribution (APD) measurement is a promising method to estimate electromagnetic interference in digital communication devices [1-4]. The APD is defined as the probability of time for which the amplitude envelope of the noise exceeds a threshold level, and has strong correlation with the bit error rate (BER) obtained in a wireless communication performance test [5]. More recently, we have proposed the APD as an efficient method to analytically detect an electromagnetic coupling path to the antenna [6-7]. We expected the superiority of the APD measurement method as compared with the conventional intensity level measurement technique on evaluation of the noise coupling to several antennas. In this paper, we presented investigation results of noise coupling from a digital-RF mixed IC acting as noise source to receiving antenna on the board using the APD method in the LTE receiver communication band.

II. EVALUATION BOARD

We fabricated a test board on which an RF-IC is mounted for demonstrating the APD method. Figure 1 shows an overall view of the board, and Figure 2 shows a schematic of a cross section of the board. The board of dimension is 170 mm horizontal x 135 mm vertical. And the IC chip of 5 mm x 5 mm in plane size has a digital circuit block as a noise generation circuit and an RF circuit block including a low noise amplifier and a mixer for In-phase/Quadrature (I/Q) signal processing in the LTE receiver communication band [8].

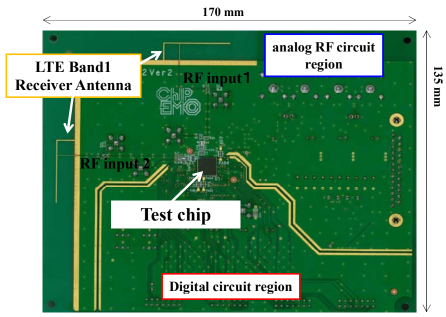

Fig. 1. Overall view of the test board

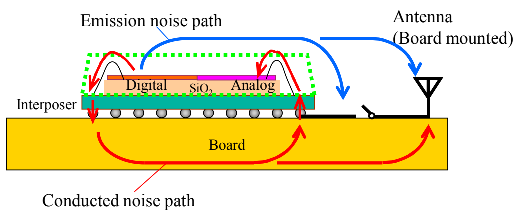

Fig. 2. Schematic of an evaluation board (cross sectional view). Arrows indicate a possible path of conduction and emission noise to RF circuit.

The IC chip was mounted on an interposer substrate of 8 mm x 8 mm and they were connected by bonding wires. Two RF receivers are integrated in the analog circuitry of the chip and two antennas designed for receiving the LTE frequency band 1 signals are connected to each input line of the RF receiver, respectively. Here, we focused about the noise coupling path from a digital circuit to an RF circuit through outside the IC chip (see Fig.2). In Fig.2, red and blue arrows indicate a possible noise coupling path from the digital to the RF circuit through the board and over the air, respectively.

III. MEASUREMENT

We measured the APD of the magnetic field above PCB. The center frequency and the bandwidth for the measurement was 2.121GHz and 5MHz, respectively, which was in the LTE receiver communication band. Figure 3 indicates a two-dimensional APD measurement system. Time series recorded by the real-time spectrum analyzer (RSA) is synchronized with a probe control system for a magnetic near-field measurement. APD curves are calculated using the time series, which are IQ data recorded during 2ms by a measuring instrument. A loop antenna of 6mm in diameter is used as a probe in the measurement with the position of 3mm above the PCB and with scanning pitch of 5mm (the measurement region is decomposed into 37-by-31 cells).

Next, to investigate the degree of noise coupling from the IC to the each antenna, we performed correlation analysis using APD curves measured at the antenna and other points on the board. Fig. 4 shows a measurement system of antenna receiving noise. The antenna, which is detached from the IC, is connected to the RSA through a coaxial cable. We utilized the APD obtained at the antenna as the standard APD and evaluated noise coupling from the IC to the antenna by analyzing degree of similarity of APD curves at the antenna and others.

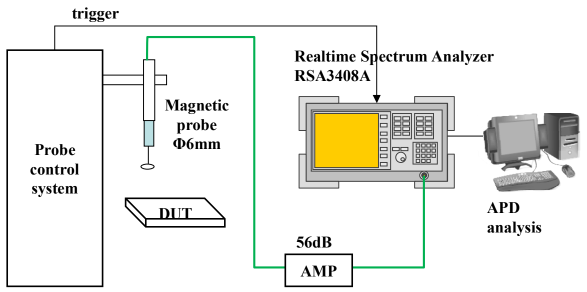

Fig. 3. 2-dimentional APD measurement system.

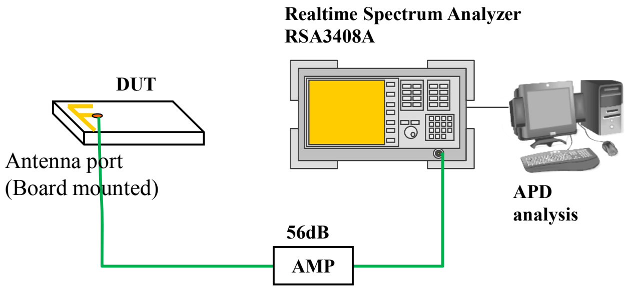

Fig. 4. Antenna receiving noise measurement system.

IV. EVALUATION RESULT

Firstly, amplitude distribution of the near-field with the peak value of the magnetic field intensity is shown in Fig.5. The high magnetic field intensity was observed nearby the IC package and from the opening and slit of a ground plane. This emission noise from ground slit suggests that the noise generated by the digital circuit in IC chip conducts to the board, and the noise coupling path to the outside of the chip exists. If RF circuit or receiving antenna is positioned at the high magnetic fields intensity point, the degradation of communication performance is predicted because of high magnetic field intensity. However, it is difficult to estimate the significantly influence on an antenna only by general radiation magnetic field intensity measurement.

The noise amplitude is generally attenuated by the propagation on the board, but the amplitude probability of noise is rarely changed. As a result, we conclude that the observation of probability parameters by using the APD method is effective for identification of a noise coupling path.

Figure 6 plots the APD curves in 2.1GHz LTE band. The APD curves A, B, and C are measured at the connected antenna1, connected antenna2 and above the IC package (at 21 x 15 cell), respectively. The APD curve B changes steeply in more than -40dBm but keeps constant probability 1 from noise amplitude of -60dBm to -40dBm area. The result of constant probability is because the noise amplitude generated by the digital circuit is almost constant in time. Meanwhile the APD curve A changes gently, because the thermal noise has varied randomly in time. Also, the APD curve C changes steeply, and the gradient of the APD curve C seems to be the tendency like that of the APD curve B. Consequently, the noise generated from the IC chip is considered to have the possibility of affecting communication through the antenna 2.

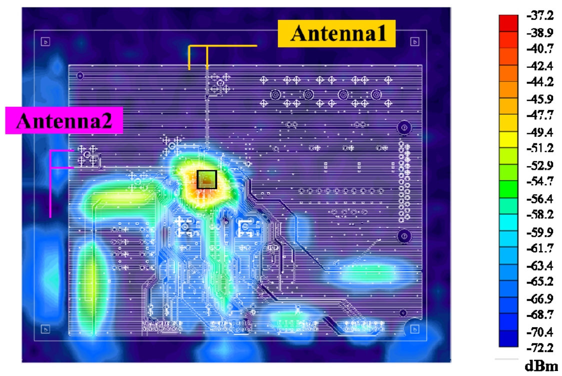

Fig. 5. Measured magnetic near-field distribution above the test board

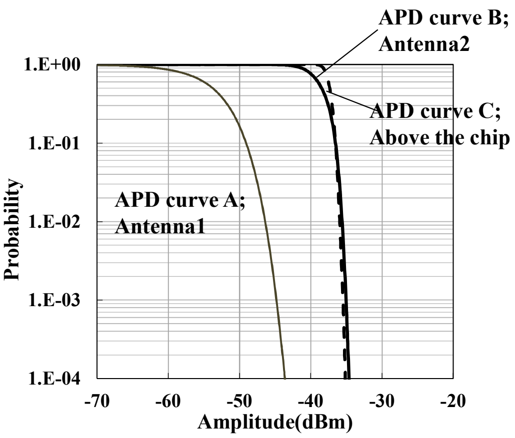

Fig. 6. Measured results of APD

V. ANALYSIS

In order to verify this consideration, we estimated analytically degree of similarity of the shape of the APD curve using a correlation coefficient. Based on sample of paired data (x_i , y_i), Pearson's product-moment correlation coefficient $r(x , y)$ is defined as follows.

$$r(x,y)=\frac{\sum_{i=1}^{n}\left(x_i-\bar{x}\right)\left(y_i-\bar{y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i-\bar{x}\right)^2}\sqrt{\sum_{i=1}^{n}\left(y_i-\bar{y}\right)^2}} \quad (1)$$

where n indicates the number of samples, and are arithmetic average of $\bar{x}$ and $\bar{y}$, respectively. In this case, the correlation coefficient r for the amplitude data of two APD curves is calculated by Eq.(1). When the shape of two APD curves was similar, a correlation coefficient indicates a high value.

The analyzed results of the distribution of the APD correlation coefficient are drawn in Fig.7 and Fig.8. Here, in Fig.7 the APD curve A at the antenna 1 (represented as x_i) is set to standard and correlation coefficients with APD curves at other points (represented as y_i) are calculated at each point using Eq.(1). Similarly, in Fig.8 the APD curve B at the antenna 2 is set to standard and correlation coefficients are calculated at each point too. As shown in Fig. 7 the high points of the correlation coefficient with antenna 1 are distributed widely on the board except the neighborhood of an IC. This result indicates that correlation with noise generated by digital circuit was low, but with thermal noise was high. Meanwhile, in Fig.8, the high points of the correlation coefficient with antenna 2 were observed nearby IC and slit of a ground plane, which means that the noise emitted from the IC chip spreads in the board and couples to the antenna 2. From the analysis results described above, we considered that the digital noise generated by IC is dominantly coupling to the antenna 2 as compared with the antenna 1 in the test board. By drawing correlation coefficient distribution on the standard of a receiving antenna, it was verified that the noise coupling to the antenna can be visualized.

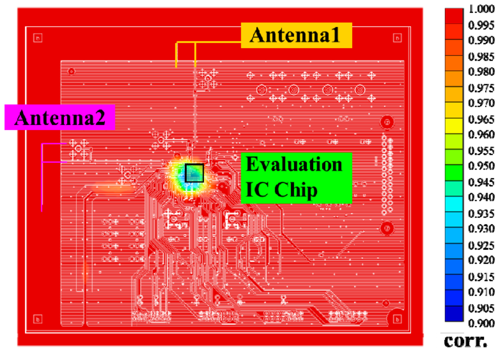

Fig. 7. Analyzed result of APD correlation coefficient distribution based on antenna 1.

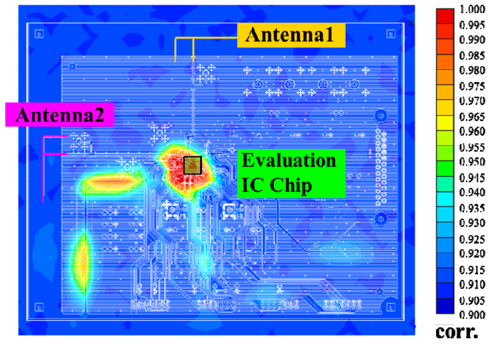

Fig. 8. Analyzed result of APD correlation coefficient distribution based on antenna 2.

Next, we confirmed this analyzed results of the noise coupling by measuring spurious level in I/Q signal output in each RF receiver. Fig. 9 shows a system for measurement of I/Q signal output from the RF circuit on the evaluation board. The board was located in an anechoic chamber and was connected to a signal analyzer for I/Q signal analysis. A clock signal of 124.803 MHz was supplied for noise generation circuit operation from outside of the chamber. An RF input signal as a receiving test signal was supplied by using transmitter dipole antenna in this experiment. Its frequency and power was 2.121 GHz and -100 dBm, respectively. If the noise coupling from the noise generation circuit to the RF circuit occurs, not only a test signal generated by RF input but also a spurious, which are amplified by a low noise amplifier and then and down-converted to the baseband by a mixer The incoming RF signal is amplified by a low-noise in the RF circuit block of IC, appear in the I/Q signal spectrum. Figure 10 shows I/Q signal spectra including DC, test signal, and spurious peaks in each receiver at baseband. These peaks were filtered with a frequency band of 5 MHz in the RF circuit block before received by the spectrum analyzer. Although the frequencies of test signal and spurious are originally about 2.1 GHz (the spurious is the 17th order harmonics of the clock for the noise generation circuit), they are down-converted by the mixer in the RF circuit of the IC.

The test signal levels inputted from external signal generator are almost the same between both receivers as a matter of course. On the other hand, the spurious level (namely coupling level) of receiver 2 was 7 dB higher than the receiver 1. Here, the spurious level difference of 7 dB does not occur by inter noise coupling in a chip, because the distance between each RF circuit integrated in the chip is very close. Therefore, the reason is influence of the noise coupling path outside the chip to RF signal line consisting of the antenna on a board. From this result, we can verified that the noise coupling to an antenna was influenced the spurious level in the LTE receiver communication band. In mixed signal IC, the noise coupling between the digital-analog circuitry in IC chip is a very serious subject [9-10]. In addition, this result shows that the noise coupling on the board also has very significantly influence.

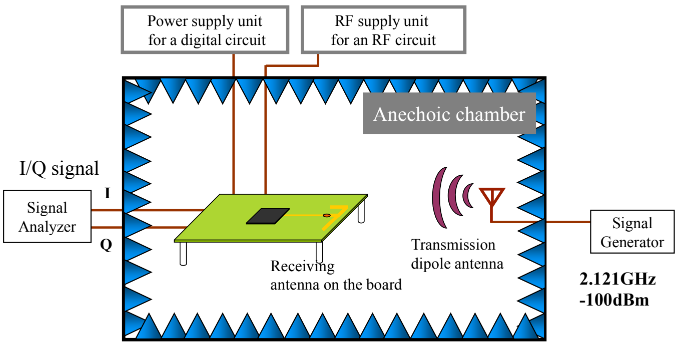

Fig. 9. System for measurement of I/Q signal output from the RF circuit on the test board

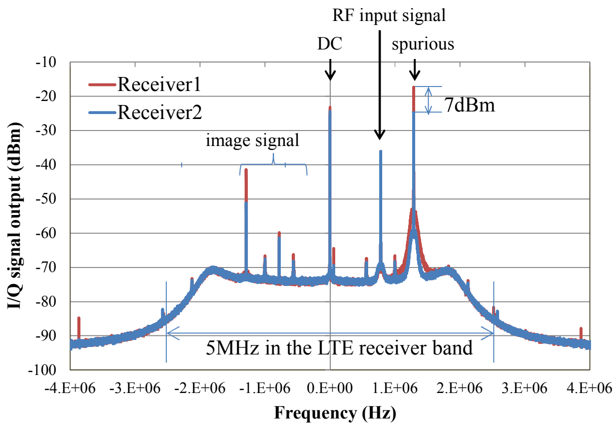

Fig. 10. I/Q signal spectrum

The cause of the difference of the noise spurious level between receiver 1 and receiver 2 is considered to be the layout difference of the boards. Formation of a ground along a signal line, so called guard trace is known as the countermeasure for the noise coupling or a cross talk. On this board, there is no guard trace on the board near the IC in the case of the receiver 2. Furthermore, the RF signal lines in the receiver 2 are close to power supply lines of the digital circuit working as a noise source. Therefore, it is considered that the noise coupling through a board from the digital circuit is stronger in case of RF input system 2. The electromagnetic-field simulation was performed to verify the effect of guard trace, and it was confirmed that the difference of the noise spurious level between both receivers became less than 7 dB when the guard trace on the board existed in both RF input systems. Since such a countermeasure on a board becomes more difficult because of the limit of design region, it seems that the noise countermeasure technology at an IC chip or a package level becomes indispensable from now on.

VI. CONCLUSION

We fabricated test board on which a digital-RF mixed IC and two antennas mounted, and evaluated the noise coupling to each antenna using APD method on the board in the LTE receiver communication band. As a result, by using the APD method the high point of correlation with the noise coupling to antenna could be visualized. And we demonstrated that APD method is effective in evaluation of the degree of noise coupling from an IC to several antennas on the board, and verified the intensity of the noise coupling to an antenna is affected greatly by layout patterns on a board.

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