Influence of Termination Impedance to Radiated Emission from AC Cable with Ferrite Cores Array below 300 MHz

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***Abstract*— The common-mode current on AC cable is one of radiated disturbance source below 300 MHz. The method of using common-mode absorbing device (CMAD) is discussed to improve reproducibility of test result by stabilizing the termination impedance of AC cable. However, CMAD can't stabilize the differential-mode impedance because this acts as a kind of common-mode choke coil. In this paper, the influence of the differential-mode termination impedance was studied. The measurement results of disturbance current on AC cable showed that the differential-mode level between AC power line and ground line is larger than the common-mode level. The study using a simple circuit model suggested that the differential-mode current could be converted to the common-mode current by changing the termination impedance between AC power line and ground line. The experiment was carried out by using the artificial AC network which has a function to change both common-mode and differential-mode termination impedance. The results showed that a common-mode level fluctuated by changing the termination impedance. The results also showed that the influence to the common-mode current and the radiated electric field strength in the case of the comb generator was smaller than that in the case of the PC.**

Keywords— Radiated disturbance test; Common-mode current; Differential-mode current

I. INTRODUCTION

The common-mode current on the AC cable of information technology equipment (ITE) is one of the radiating disturbance sources below 300 MHz. Stabilizing the termination impedance of the AC cable to the ground plane is effective to improve the test results deviation between test sites [1]. The VHF band line impedance stabilization network (VHF-LISN) [2]-[4] and the common-mode absorbing device (CMAD) [5]-[7] are investigated as the devices for stabilizing the termination impedance to the reference ground plane.

The investigation results pointed out that the deviation in the case of VHF-LISN was smaller than that in the case of CMAD [4]. The reason why the deviation difference appears between CMAD and VHF-LISN should be investigated because the common-mode current on the AC cable is the main disturbance sources and both VHF-LISN and CMAD stabilize the termination impedance of the common-mode current.

Both differential-mode and common-mode current exists on the AC cable, and the common-mode current is the main disturbance source. However, the differential-mode current is converted to the common-mode current, and the rate is due to the differential-mode termination conditions of the AC cable. This might be the reason why the deviation in the case of the CMAD is larger than the deviation in the case of VHF-LISN because the CMAD does not stabilize the termination impedance of the differential-mode current.

In this paper, the influence of the differential-mode termination impedance to the conversion factor between common-mode and differential-mode is studied. The first, the differential-mode and common-mode current levels are measured for three types of equipment to investigate the level difference. Second, a simple circuit model is developed, and the influence of the differential-mode impedance is investigated. Finally, the artificial AC network whose termination impedance can be changed is developed, and the relation between termination impedance and radiated electric field is investigated.

II. MEASUREMENT OF CURRENT ON AC CABLE

A. Radiation mechanism at low frequency range

Figure 1 shows one of the radiation mechanisms in low frequency range. In this frequency range, as shown in Fig. 1(a), one of the radiation sources is the AC cable because the length of AC cable is longer than the size of equipment under test (EUT). Figure 1(b) shows the calculation example at 180 MHz. In this example, EUT was presented by the printed circuit board with voltage source and the AC cable was modeled by the parallel wires. The EUT was placed at the height of 80 cm from the ground plane. The white area is the high intensity area of the common-mode current. This shows that the AC cable is major radiation source because the common-mode current is higher than the level at the PCB area.

When the AC cable is the radiation source, the termination impedance of the AC cable, Z_T, should be stabilized because the value affects the current distribution on the cable. One of the methods uses the CMAD [5], [6]. Figure 2 shows the method of stabilizing the common-mode impedance by CMAD. In this method, since the CMAD acts as a common-mode choke coil, the influence of the common-mode impedance, Z_{ct}, is reduced by the high impedance of the choke coil.

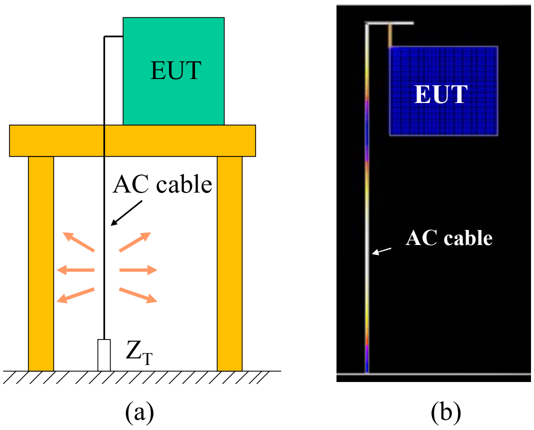

Fig. 1 Radiation mechanism at low frequency range

As shown in Fig. 2, EUT is the source of both differential-mode and common-mode current. In this paper, the current between wires carrying AC power and frame ground wire is defined as the differential-mode current. Moreover, the current between whole AC cable and reference ground plane is defined as the common-mode current. The differential-mode current is affected by the differential-mode termination impedance, Z_{dt}, because the CMAD can't reduce the influence of the impedance, Z_{dt}. This means that the radiated disturbances are affected by the differential-mode termination impedance if the conversion factor from the differential-mode to the common-mode is changed by the differential-mode termination impedance.

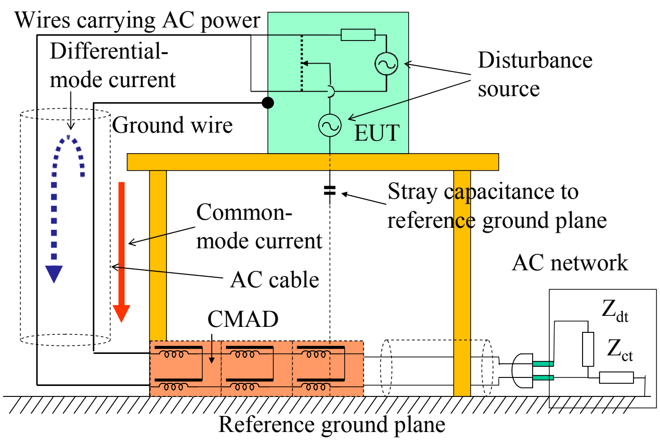

Fig.2 Common mode impedance stabilization method of using CMAD

B. Measurement of disturbance current

The disturbance current was measured to investigate the ratio of the differential-mode and the common-mode current. Figure 3 shows the measurement points of the current. As shown in this figure, the AC cable with three wires was used for the experiment. In this paper, these wires were called as W wire, B wire, and G wire from the color of each wire. In these wires, W and B wire are used for transmission of AC power, and G wire is used for frame ground.

A current probe was used to measure the disturbance current. Although eight conditions are considered for the measurement, three conditions in Fig. 3 were selected for the measurement as the typical conditions. In these conditions, the condition "B" is the method for measuring the disturbances of the wires which is connected directly to the electronics circuit such as switching regulator and inverter, the condition "BW" is the method for measuring the disturbance appearing between EUT frame ground and the electronics circuit, and the condition "BWG" is the method for measuring the common-mode current which is appearing between the wires and the reference ground plane as shown in Fig. 2.

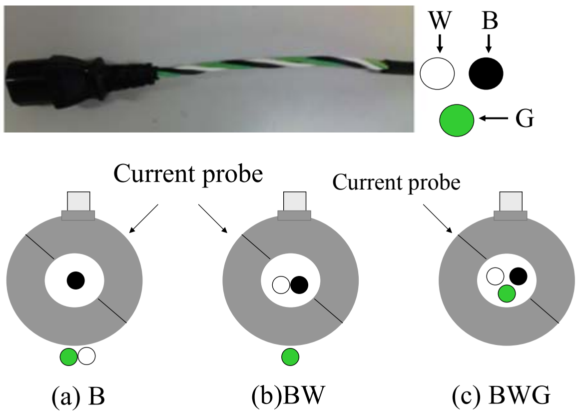

Fig. 3 Measurement condition of disturbance currents

Measurement results are shown in Fig. 4. The comb generator, a PC, and a switching regulator were used for the experiment. Here, the comb generator is the same type generator which was used for the comparability among sites [4]. In this figure, the vertical axis is the mean value of the deviation from the measurement value of the common-mode current.

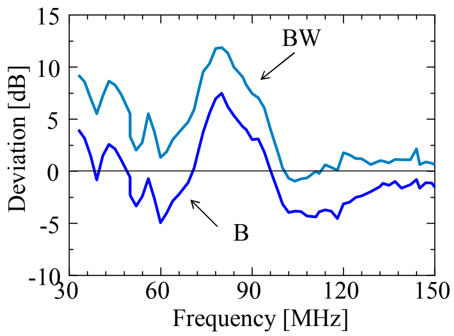

Fig. 4 Measurement example of disturbance current

This shows that the current on B wire is similar to the value of the common-mode current but the current on BW wires is larger than the value of the common-mode current. This means that the differential mode current (i.e. current on BW) is larger than the common-mode current in many cases.

C. Analysis of conversion factor from differental-mode to common-mode

Experimental results showed that the large differential-mode current exists in many cases. If the conversion factor is affected by the differential-mode termination impedance, the common-mode level is changed by the differential-mode impedance. As a result, the radiated field strength is affected by the change of the differential-mode impedance because the main source of the radiated electric field is the common-mode current. Therefore, the relation between the conversion factor and the differential-mode termination impedance was studied by using a simple circuit model.

The analysis model is shown in Fig. 5. In this figure, Z_{i11} and Z_{i22} present the internal impedance between each wire port and the reference ground plane, and Z_{i12} is the internal impedance between BW port and frame ground (i.e. G) port. E_1 and E_2 are the disturbance source which is presented by the differential-mode voltage V_d and the common-mode voltage V_c. Z_{o11}, Z_{o12}, and Z_{o22} is the input impedance at the output ports of EUT. Z_{o11} and Z_{o22} are the impedance between each wire and the reference ground plane, and the Z_{o12} is the impedance between BW wire and G wire.

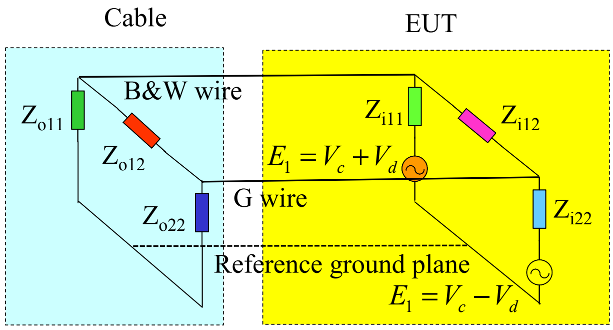

Fig. 5 Analysis model of conversion factor

Analysis result by using circuit in Fig. 5 is shown in Eq. (1)

$$I_c = V_c\left[\frac{1}{Z_{a4}+Z_{o11}}\left\{1+\frac{Z_{a4}}{Z_{a3}}\frac{Z_{a1}}{Z_{i22}}\right\}+\frac{1}{Z_{b4}+Z_{o11}}\left\{1+\frac{Z_{b4}}{Z_{b3}}\frac{Z_{b1}}{Z_{i22}}\right\}\right] \quad (1)$$
$$+V_d\left[\frac{1}{Z_{a4}+Z_{o11}}\left\{1+\frac{Z_{a4}}{Z_{a3}}\frac{Z_{a1}}{Z_{i22}}\right\}-\frac{1}{Z_{b4}+Z_{o11}}\left\{1+\frac{Z_{b4}}{Z_{b3}}\frac{Z_{b1}}{Z_{i22}}\right\}\right]$$

Here,

$$Z_{a1}=\frac{Z_{o22}Z_{i22}}{Z_{o22}+Z_{i22}},Z_{a2}=\frac{Z_{o12}Z_{i12}}{Z_{o12}+Z_{i12}},Z_{a3}=Z_{a1}+Z_{a2},Z_{a4}=\frac{Z_{a3}Z_{i11}}{Z_{a3}+Z_{i11}} \quad (2)$$
$$Z_{b1}=\frac{Z_{o11}Z_{i11}}{Z_{o11}+Z_{i11}},Z_{b2}=\frac{Z_{o12}Z_{i12}}{Z_{o12}+Z_{i12}},Z_{b3}=Z_{b1}+Z_{b2},Z_{b4}=\frac{Z_{b3}Z_{i22}}{Z_{b3}+Z_{i22}}$$

In this equation, I_c is common-mode current. This suggests that the common-mode current is affected by the differential-mode termination impedance because Z_{o12} is the function of the differential-mode termination impedance.

III. EXPERIMENT

A. Experimental set-up

The experiment was carried out to confirm the analysis results. The experimental set-up is shown in Fig. 6. In the experiment, the CMAD was replaced by the ferrite cores array which can exhibit the similar effect of CMAD [8]. Seventeen ferrite cores were used for the experiment according to the reference [8]. The AC cable was terminated by the VHF-LISN [4] for stabilizing the termination impedance. The artificial AC network (A.N.) was inserted between the ferrite cores array and the VHF-LISN.

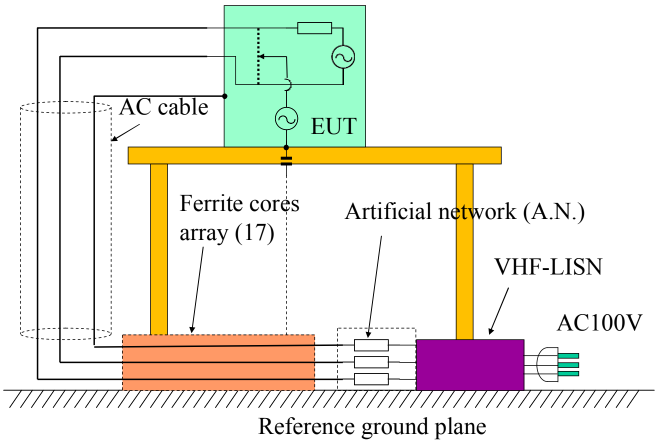

Fig.6 Experimental set-up for measuring influence of termination impedance

Configuration of A.N. is shown in Fig. 7. The A.N. is constructed with a parallel resonance circuit because the transmission line which is constructed with AC cable and reference ground plane acts as a resonance circuit. In the experiment, the electric field strength and the current intensity were measured on the condition that EUT is the comb generator and the PC. In this measurement four circuits in Fig. 7 were inserted as the A.N. one after another.

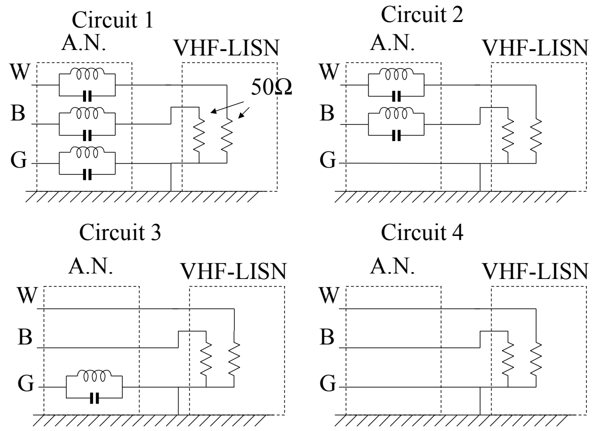

Fig. 7 Circuit diagram of A.N.

B. Measurement results

The measurement results of disturbance current are shown in Fig. 8. In this figure, the vertical axis is the standard deviation of the level deviation from the level in which the circuit 4 in Fig. 7 was inserted to the set-up in Fig. 6.

This shows that the standard deviation at the current between BW wires and G wire is larger than that of the common-mode current. This means that the influence of the termination impedance for the differential-mode is larger than that of the common-mode current. For the common-mode current, the standard deviation is reduced from 7.5 dB to 3 dB in the case of PC, and the deviation is reduced from 7 dB to 1 dB in the case of the comb generator. The reason why the deviation reduced significantly in the case of comb generator is future problem.

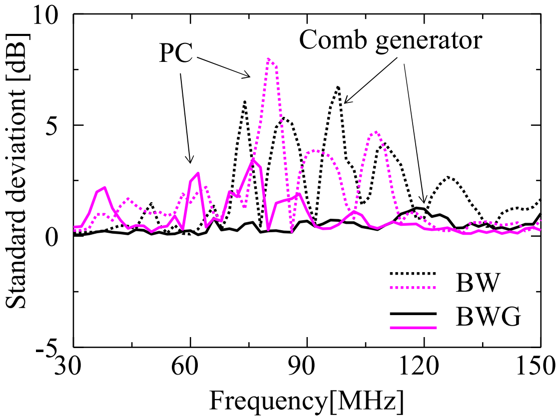

Fig. 8 Influence to measurement results of current by changing termination impedance

Figure 9 shows the measurement result of the radiated electric field strength. The vertical axis is the standard deviation of the level deviation from the level in which the circuit 4 in Fig. 7 was inserted to the set-up in Fig. 6. When the comb generator was used as the disturbance source, the deviation is within 1dB. However, the deviation is more than 3

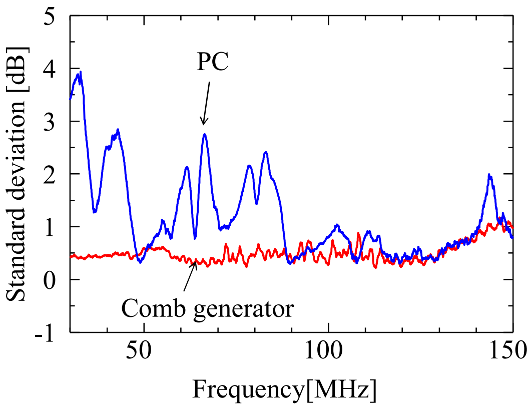

Fig. 9 Influence to measurement results of radiated electric field strength by changing termination impedance

dB when PC was used as the disturbance source. These suggest the following results;

(1) The termination impedance AC main cable is affected to the radiated field strength. Considering with the characteristics of CMAD, the influence might be caused by the differential-mode termination impedance.
(2) The influence is changed by the type of the equipment. This is closely related to the standard deviation of the common-mode current.

IV. CONCLUSION

Influence of differential-mode termination impedance to radiated electric field was investigated. The measurement results of the disturbance current showed that the differential-mode current (i.e. current between BW wires and G wire) was larger than the common-mode current in many cases.

The analysis using the simple circuit model suggested that the contribution to the common-mode from the differential-mode was changed by the differential-mode termination impedance. The experiment using artificial AC networks showed that the change of the differential-mode termination impedance affected the standard deviation of measured level and the influence depends on the type of the equipment.

These results suggest that the CMAD is insufficient device to improve the site correlation because the radiated emission level is affected by the differential-mode termination impedance depending on the kind of EUT.

In the future, we should evaluate the reason why the influence is changed by the kind of the equipment.

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