Measurement of Radiated EM Field Intensity and Effect of Electrode Condition due to Low Voltage ESD

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***Abstract* — Micro-gap discharge shows very fast transition duration of about 32 ps or less. Besides, breakdown field strength was examined to corroborate the very fast transition durations of about 32ps. Also, a relationship between breakdown field strength and radiated electromagnetic field intensity was examined in experimental study. As a consequence of the experiment using the system, the breakdown field strength was very high of about 80 MV/m in low voltage discharging of below 350V. And so, the average electromagnetic field intensity is proportion to the breakdown field strength in under the maximum electromagnetic field intensity. In addition, maximum radiated EM field intensity shows approximately 3.5Vp-p respectively, the field radiation due to micro gap discharge has the some limit value in the maximum. And so, the electrode surface effect was confirmed that the received electromagnetic field intensity has a cyclic variation with the cleaning of electrode surface. The radiated electromagnetic field intensity was sudden increase just after the cleaning.**

I. Introduction

Fast transients of electromagnetic field are arisen from gap discharges of ESD (electrostatic discharge) and electrical contacts. The transient due to gap discharge is a very wide band (high frequency) electromagnetic noise source. Over the past few years a considerable number of studies have been made on electromagnetic noises of the ESD and contacts from the point of view of the electromagnetic compatibility. The electromagnetic noise characteristics of gap discharge are gradually becoming clearer [1]-[7].

However, there has been only a little amount of information about measured voltage or current waveforms of the transition duration (voltage rise time and current rise time) due to a starting of the discharge in very wide band time domain [8]-[11]. Very little is known about characteristics of the transition duration due to the ESD and the gap discharge.

The main purpose of this study is to illuminate a relationship between the electromagnetic noise characteristics and the discharge phenomenon as the EMI source. Up to now we were set up an experimental system using the distributed constant lines to observe the transition durations due to low voltage gap discharge, because the transients are very rapid. It was possible to observe the voltage waveform and the frequency distribution of transition durations in 6GHz [12]-[13]. Thereafter, the measurement system was improved on the band width from 6GHz to 12GHz using new coaxial electrode system. In the new system, the voltage and current waveforms were measured by an electric field sensor (infinitesimal monopole antenna), and a magnetic field sensor (infinitesimal loop antenna) respectively. The insertion loss of the coaxial electrode system was within about -3dB in frequency range below 12GHz. It was confirmed that voltage and current rise times of transition duration showed 32 ps or less [14].

Then, breakdown field was examined to corroborate the very fast transition durations of about 32ps. Gap length characteristics and breakdown field strength were examined in experimental study. The breakdown field strength was calculated by the gap length characteristics. The breakdown field was very high of about 80 MV/m in low voltage discharging of below 350V. In low voltage discharge, the breakdown field strength level is higher than a general discharge [15].

In this paper, the relationship between breakdown field strength and radiated electromagnetic field intensity was confirmed in experimental study. And so, we confirmed that the electrode effect of surface condition due to low voltage micro gap discharge affects a radiated electromagnetic field intensity.

II. Characteristics of The Gap Length and Breakdown Field Strength

Figure 1 shows a longitudinal section view of the micro-gap discharge experimental system as low voltage ESD. The system consists of a power supply (400V-1kV), source side coaxial semi-rigid cables (below 1m) with a needle electrode and a tapered coaxial electrode. In the experiment, gap length due to breakdown was measured by a micro meter head which have one micro meter resolution. Then, the gap length was decided by average value of over one hundred experiments. The breakdown field strength was calculated by the gap length characteristics. Figure 2 shows a photograph of the gap length characteristics measurement system. In this experiment, a digital indicate micro head was used to measurement the gap length characteristics.

Figure 3 shows the relationship between the discharge voltage and the gap length. In the figure, horizontal axis shows the discharge voltage from 300V to 800V, vertical line shows the gap length. These data indicate an average value of about 70 to 100 measurements. The circle symbol is gap length in 0.1mm radius of curvature of the needle electrode, triangle symbol is 0.5mm radius of curvature of the needle electrode. The gap length characteristic was increased in proportion to the discharge voltage. In the 326V of minimum discharge voltage, the gap length was 4 micro meters.

The breakdown field E V/m was calculated by equation (1).

$$E = V / d \text{ [V/m]} \qquad (1)$$

Where, E is breakdown field, V is discharge voltage, and d is the gap length.

The calculated breakdown field characteristic was shown in Fig.4. In the figure, horizontal axis is the discharge voltage from 300V to 800V, vertical line is the breakdown field due to discharging. In high voltage of about 450V to 700V, the breakdown fields were shown about 20 MV/m as constant.

While in low voltage of below 350V, the breakdown field was increased to high field strength in suddenly. In the 326V of minimum discharge voltage, the breakdown field was reached to about 80 MV/m.

III. The Relationship Between Breakdown Field and Radiated Electromagnetic Field Intensity

The breakdown field showed very high strength value of about 80 MV/m in the 326V discharge. In low voltage discharge, the breakdown field strength level is higher than a general discharge.

A. Relationship Between Breakdown Field Strength and Radiated Electromagnetic Field Intensity

Then, a relationship between the breakdown field strength and radiated electromagnetic field intensity was examined in experimental study. Figure 5 shows a measurement system of the radiated electromagnetic field intensity due to the low voltage discharging. The measurement system has two construction part, these are a radiation part and a detection part. The radiation part consists of a high voltage D.C. power supply and dipole electrode elements with the discharge gap. The electrode elements were made by brass sticks, length of

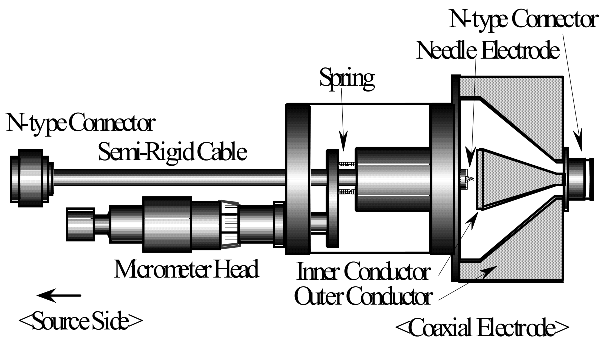

Fig.1. longitudinal section view of the tapered coaxial electrode

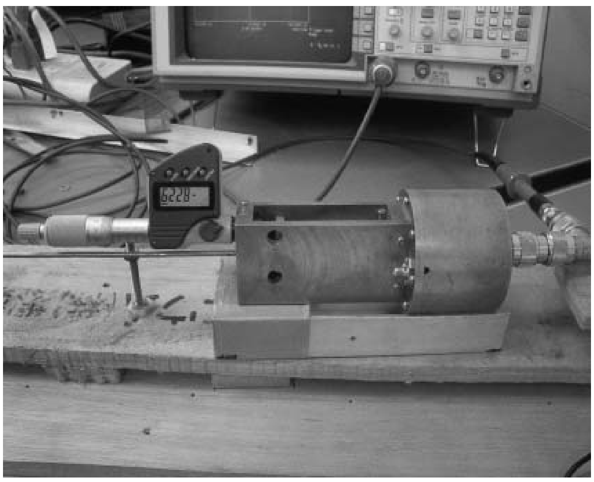

Fig.2 Experimental setup of gap length measurement system.

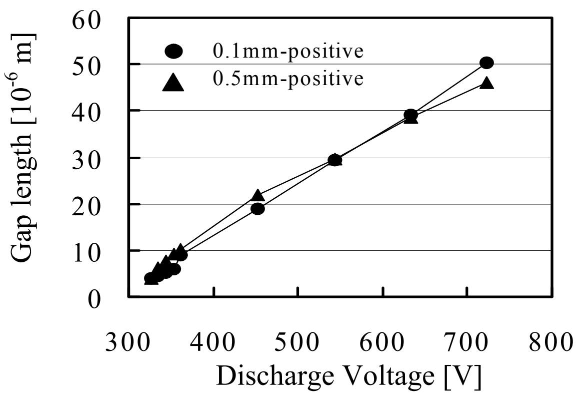

Fig.3 Relationship between discharge voltage and gap length

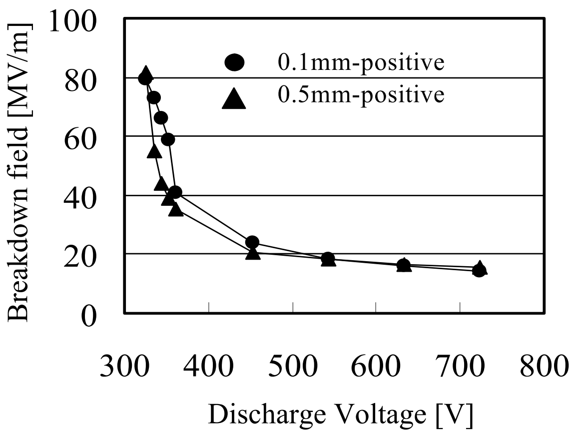

Fig.4 Relationship between discharge voltage and breakdown fields

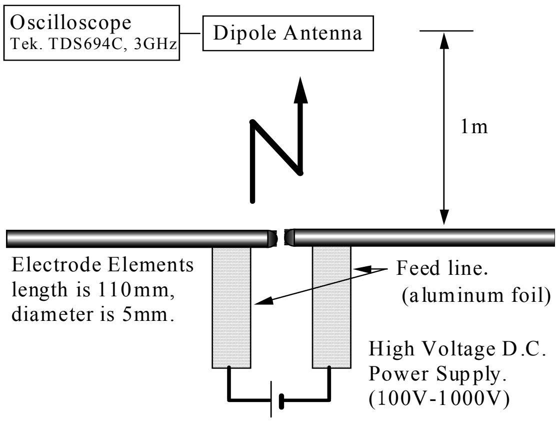

Fig.5 Measurement system of the radiated electromagnetic field intensity

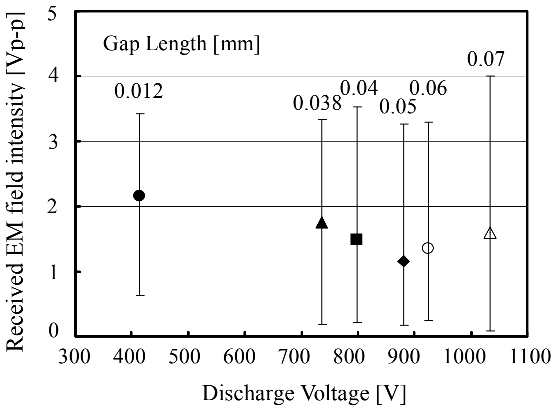

Fig.6 The relationship between breakdown voltage and radiated electromagnetic field intensity. (Voltage value measured by oscilloscope)

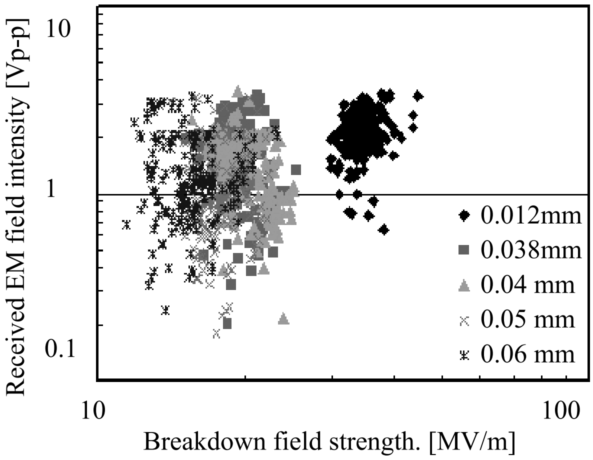

Fig.7 The relationship between breakdown field strength and radiated electromagnetic field intensity. (Voltage value measured by oscilloscope)

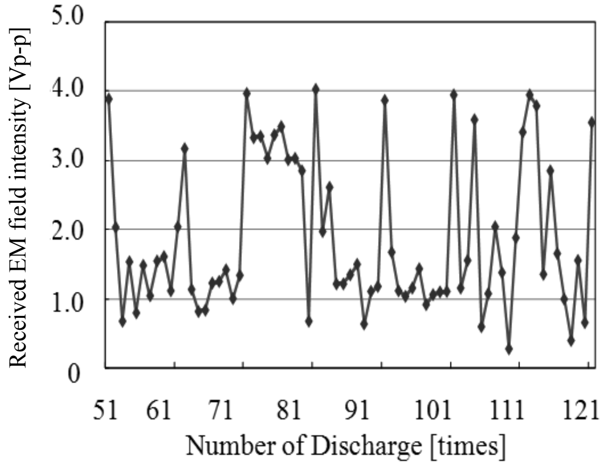

Fig.8 Electrode surface effect of the gap discharge with periodically cleaning of the gap electrode every ten discharge. (Gap length is 0.038 mm, Number of discharge is from 51th to 121th of 200 discharges)

an element is 110mm, diameter is 5mm, and radius of curvature of the electrode element is 2.5mm, respectively. Resonant frequency of the electrode elements is about 680MHz. Power source supplied to the electrode elements with aluminum foils as the feed line. The gap length is 0.012 mm, 0.038 mm. 0.04mm, 0.05 mm, 0.06 mm and 0.07 mm.

The detection part consists of a dipole antenna and digitizing oscilloscope (Tektronix TDS694C, 3GHz, 10GS/s). The dipole antenna has resonance frequency accord with 680 MHz of the electrode elements. The detectible dipole antenna was set near the electrode elements, distance is 1m. This experimental system constructs at a normal laboratory environment, which has not the electromagnetic field isolation and an air control system.

In the experiments, a gap length is set at 0.012mm, 0.038mm, 0.04mm, 0.05mm, 0.06mm, and 0.07mm. The source voltage of the DC power supply is increased slowly. When discharge occurred, the radiated electromagnetic field intensity was measured by the oscilloscope with the dipole antenna in time domain. The electromagnetic field intensity was expressed by the measured peak-to-peak voltage value of the oscilloscope.

Figure 6 shows an experimental result of the relationship between breakdown voltage and radiated electromagnetic field intensity value. Horizontal axis shows the breakdown voltage, and vertical axis shows the voltage measured by the oscilloscope in each gap length. The received field intensity values were expressed average value of two hundreds (200) experiments. In small gap of 0.012mm, discharge voltages are about 410V, the voltage of field intensity measured by the oscilloscope is about 2.2Vp-p. While in 0.05mm gap length, discharge voltages are about 880V, field intensity values are a low density of about 1.4Vp-p. The relationship between breakdown voltage and radiated electromagnetic field intensity has not proportional relation. It is confirmed that the radiated electromagnetic field intensity value in voltage discharge of about 400V is higher than that of the voltage discharge of about 900V.

The relation of the breakdown field strength and the radiated electromagnetic field intensity value are shown in Fig.7. Horizontal axis shows the breakdown field strength, and vertical axis shows the voltage measured by oscilloscope. This experimental result has two typical characters. In first, maximum voltage shows approximately 3.5 Vp-p respectively, the electromagnetic field radiation due to micro gap discharge has the limit value in the maximum. In second, the average electromagnetic field intensity value was rise due to increase of the breakdown field. Then, the average electromagnetic field intensity is proportion to the breakdown field value.

B. Electrode Surface Effects

Figure 8 shows electrode surface effects of the gap discharge with periodically cleaning of gap electrode. The gap electrodes clean every ten discharges. The cleaning process is polish using a compound cream and washing of industrial alcohol. In the figure, horizontal axis is number of discharges from 51 th to 121 th in tow hundred (200) discharge, and vertical line is received electromagnetic field intensity Vp-p [V]. In result, the received electromagnetic field intensity has a cyclic variation of ten discharges. The radiated electromagnetic field intensity is sudden increase just after the cleaning. It is deliberate that the breakdown field strength is very high by the uniform electric field in symmetrical electrode in just after the cleaning.

IV. Conclusion

The relation between breakdown field strength and radiated electromagnetic field intensity was confirmed.

As a consequence of the experiment using the system, the breakdown field was very high strength of about 80 MV/m in low voltage discharging of below 350V. The relationship between breakdown voltage and radiated electromagnetic field intensity was confirmed. The radiated electromagnetic field intensity value in voltage discharge of about 400V was higher than that of the voltage discharge of about 900V.

Also, the relation of the breakdown field strength and the radiated electromagnetic field intensity were confirmed. Maximum radiated electromagnetic field intensity value shows approximately constant value respectively, the electromagnetic field radiation due to micro gap discharge has the some limit value in the maximum. And so, the average electromagnetic field intensity is proportion to the breakdown field value in under the maximum electromagnetic field intensity value.

Besides, the electrode surface effects were confirmed that the received electromagnetic field intensity has a cyclic variation with the cleaning of electrode surface. The radiated electromagnetic field intensity is sudden increase just after the cleaning. It is deliberate that the breakdown field strength is very high by the uniform electric field in symmetrical electrode in just after the cleaning.

References

[1] P.F.Wilson and M.T.Ma, Field radiated by electrostatic discharges, IEEE Trans. on EMC, EMC-33, no.1, pp.10-18, Feb. 1991.

[2] M. Honda, "Indirect ESD measurement using a short monopole antenna, 1990 IEEE Int'l. Symp. on Electromagn. Compat., pp.641-645, Aug.1990.

[3] L.M.MacLeod and K.G.Balmain,Compact Traveling-Wave Physical Simulator for Human ESD, IEEE Trans. on Electromagn. Compat., vol. 39, no. 2, pp. 89-99, May 1997.

[4] D.Pommerenke:ESD:transient fields, arc simulation and rise time limit, Journal of ELECTROSTATICS, vol.36, pp.31-54, 1995.

[5] R.Zaridze, D.Karkashadze, R.G.Djobava, D.Pommerenke, and M.Aidam, Numerical Calculation and Measurement of Transient Fields from Electrostatic Discharge, IEEE Trans. on Components, Packaging, and Manufa. Tech., Part C, vol.19, no.3, July 1996.

[6] O.Fujiwara, An Analytical Approach to Model Indirect Effect Caused by Electrostatic Discharge, IEICE Trans. on Commun., vol.E-79-B, no.4, April 1996.

[7] S.Ishigami, R.Gokita, Y.Nishiyama, I.Yokoshima and T.Iwasaki:Measurements of fast transient fields in the vicinity of short gap discharges, IEICE Trans. on Commun., vol.E78-B, no.2, pp.199-206, Feb. 1995.

[8] K.Arai, W.Janischewskyj and N.Miguchi ,Microgap Discharge Phenomena and Television Interference, IEEE Trans.Power Appar.&Syst.,PAS-104,No.1, 1985.

[9] D.Pommerenke:ESD:waveform calculation, field and current of human and simulator ESD, Journal of ELECTROSTATICS, vol.38, pp.31-54, 1996.

[10] B.Daout and H. Ryser, The reproducibility of the rising slope in ESD testing, Proc. of 1986 IEEE Int'l Symp. on Electromagn. Compat., pp.467-474, Aug.1986.

[11] R.Wallace, 6GHz time Domain Measurement of Fast Transient Events, Proc. of 1992 IEEE Int'l Symp. On Electromagn. Compat., pp.460-463, Aug.1992.

[12] K.Kawamata, S.Minegishi,A.Haga and R.Sato, A Measurement of Very Fast Transition Durations Due to Gap Discharge in Air Using Distributed Constant Line System, IEEE Trans. On EMC., vol.41, no.2, pp.137-141,May 1999

[13] K. Kawamata, S. Minegishi and A. Haga, Wideband Measurement of transition duration and frequency spectra due to small gap discharge as low-voltage ESD, Journal of ELECTROSTATICS, 62, pp.185-193, 2004

[14] K.Kawamata,S.Minegishi, A.Haga and O.Fujiwara, "12GHz Real Time Measurement of Voltage Rise Time and Current Rise Time Due to Micro Gap Discharge in Voltage Below 1kV", Proc. of International Symposium on Electromagnetic Compatibility Europe, Spain, pp.107-110 (Sept. 2006)

[15] K.Kawamata, S.Minegishi, A.Haga and O.Fujiwara,"12GHz measurement of transition duration and breakdown field due to low voltage ESD", proc. of 18th Inta'l Zurich Symposium on EMC,I.A.F.-4,Munich(2007)