A MODEL OF ELECTROSTATIC DISCHARGE AS ELECTROMAGNETIC RADIATION SOURCE

Lira Hamada, Takaaki Sugiyama and Takashi Iwasaki
Department of Electronic Engineering, The University of Electro-Communications
E-mail: hamada@snow.ee.uec.ac.jp

Abstract: A model for the electromagnetic field source radiated from the electrostatic discharge (ESD) in a small gap is proposed.
Key words: Electrostatic discharge (ESD), small gap, waveform reconstruction, complex antenna factor, radiation model.

1. Introduction

Electromagnetic fields radiated by electrostatic discharges (ESD) are major sources of electromagnetic interference, because such fast transient fields may cause severe malfunction in the equipment even though the average power is low. Therefore, the clarification of the static electricity phenomenon is an important issue, and various study concerning ESD have been conducted in view of electromagnetic fields [1] – [3].
In this paper, the electromagnetic radiation field by the small gap discharge that imitates ESD is examined. Then, we present a model for the radiation source from the measured electromagnetic fields.

2. Experimental setup

The overview of experimental setup is depicted in Fig. 1. The discharge apparatus is composed of capacitor, resistance, the transmission line and the rod electrode fed by a DC high-voltage supply, and they are mounted on the ground plane. The discharge occurs at a small gap between the rod electrode on the transmission line side and the ground plane. A high-resolution DC-mike actuator (PI Polytec, M227.10) is mounted under the ground plane right under the rod electrode, and is used for the small gap adjustment. A small monopole antenna and a small loop antenna are used as the field sensor to observe the radiation field by the discharge. Chip resistor is inserted in each field sensor as shown in Figs. 2 and 3. The dimensions of the sensors are tabulated in Table I. These field sensors are installed at the distance of 20mm from the rod electrode. The observation system is composed of a waveform digitizer (Tektronix SCD5000) of 4.5GHz bandwidths, and an amplifier of 5.1GHz bandwidths. Because the waveform digitizer has only one input channel, the field sensor is switched in each measurement according to the object (the electric field and the magnetic field).

2. Reconstruction of electromagnetic field waveforms using complex antenna factor

To observe fast transient radiation fields, the authors have been developed a technique for reconstructing electromagnetic waveform in time domain using the complex antenna factor (CAF) [2] - [4].
For a receiving antenna, the CAF, in which the phase information is added to the conventional antenna factor, is defined as follows:

$$F_E(\omega) = \frac{E(\omega)}{V_m(\omega)} \tag{1}$$

where ω is the angular frequency, $E(\omega)$ is the complex electric field of the incident plane wave to the antenna element, and $V_m(\omega)$ is the complex matched output voltage at the matched load Z_0 (See Fig.4). $F_E(\omega)$ can be measured by using the 3-antennta method [2]. The voltage $V_m(\omega)$ in frequency domain is the Fourier transform of the measured output voltage $v_m(t)$. Therefore, the incident electric field waveform is given by

$$E(t) = \mathcal{F}^{-1}[F_E(\omega)\mathcal{F}\{v_m(t)\}] \tag{2}$$

where $\mathcal{F}$ and $\mathcal{F}^{-1}$ stand for the Fourier transform and the inverse Fourier transform, respectively.
For the magnetic filed case, M-CAF is defined in a similar fashion. The M-CAF $F_H(\omega)$ is given by (See Fig. 5):

$$F_H(\omega) = \frac{H(\omega)}{I(\omega)} = \frac{Z_0 H(\omega)}{V_m(\omega)} \tag{3}$$

where $H(\omega)$ is the incident magnetic field to the antenna element, and $I(\omega)$ is the Fourier transform of the antenna current $i(t)$. This equation gives the magnetic waveform $H(t)$ as follows:

$$H(t)=\mathcal{F}^{-1}\left[\frac{F_H(\omega)\mathcal{F}\{v_m(t)\}}{Z_0}\right] \tag{4}$$

Because the CAFs of the field sensors may diverge in low frequency, Eqs. (2) and (4) are changed to

$$E(t)=\int_0^t \mathcal{F}^{-1}[F_E(\omega)\mathcal{F}\{v_m(t)\}]dt \tag{5}$$

$$H(t)=\int_0^t \mathcal{F}^{-1}\left[\frac{j\omega F_M(\omega)\mathcal{F}\{v_m(t)\}}{Z_0}\right]dt \tag{6}$$

In the 3-antenna method, two of three antennas (# i and # j) are positioned as transmitting and receiving antennas. Then the transmission S-parameter A_{ji} between the transmitting antenna # i and the receiving antenna # j is measured. The suffices are corresponding to the antenna numbers:

$$A_{ji}=[S_{21}]_{\#i\to\#j} \tag{7}$$

All sets of two antennas among three give three equations to calculate the CAF of each antenna in terms of A_{ji}. For example, the CAF of the antenna # 1, $F_{E1}(\omega)$, is calculated from the measured A_{ji} as follows:

$$F_{E1}(\omega)=\sqrt{\frac{j2\eta_0 A_{32}\exp\{-j\beta r\}}{\lambda Z_0 A_{21}A_{13}r}} \tag{8}$$

where r is the distance between the antennas, η_0 is the wave impedance of free-space, λ is the wavelength and β is the wavenumber of the incident field.
Similarly, $F_{M1}(\omega)$ of the receiving loop antenna # *1* is obtained as follows:

$$F_{M1}(\omega)=\sqrt{\frac{2Z_0 A_{32}\exp\{-j\beta r\}}{j\eta_0\lambda A_{21}A_{13}r}} \tag{9}$$

The CAFs of the sensors multiplied by $j\omega$ are displayed in Figs. 6 - 9.

3. Results and discussion

The reconstructed electromagnetic fields for the applied voltage of 1000 V (gap length is 97 μm) are shown in Figs.10 and 11. After 5.173ns from the initial peak of discharge radiation, the reflection from the end of the transmission line was observed in both figures. Moreover, the magnitude of the reflection peak for the magnetic field is larger than that for the electric field. Here, consider the relation between the electric field and the magnetic field. In far field, the ratio of the electric field to the magnetic field, or the wave impedance η_0 is approximately 377 Ω. Then, the ratio of the electric field to the magnetic field read from Figs.10 and 11 is 391 at the moment of discharge, and this is close to the wave impedance in far field. Therefore, the radiation fields at this moment can be considered as the far field in the area where the distance of the discharge electrodes and the field sensor is very short to 2cm. That is, this result states that the radiation source is modeled as a very small dipole-like antenna at the moment of the discharge.
Next, we should notice that the peaks by the reflection from the end of the transmission line in both figures. At this moment, the ratio of the electric field to the magnetic field is much smaller than 377 Ω, and the reflection in the magnetic field is larger than that in the electric field. Here, consider the near field radiation. In the near field radiated from a dipole source, the electric field is larger than the magnetic field. To the contrary, the magnetic field is larger than the electric field in the near field for a loop source. Consequently, because the reflection in the magnetic field is larger than that in the electric field, this result indicates that the field observed at this moment is near field by a large loop-like antenna source. In a word, the radiation source is modeled as a loop-like antenna that is larger than the moment of the discharge.
In summary, these results indicate the possibility of that the radiation model changes depending on the time at/after the discharge. First, the electromagnetic field source seems to be a very small dipole antenna model at the moment when the air between the small gap causes the dielectric breakdown and the discharge radiation occurred. Then, once the discharge occurred and the gap is electrically shortened, it can be considered as a larger loop antenna model.

7. Conclusion

In this study, we have examined about a radiation model for the small gap discharge. The results demonstrate the possibility that the model of the electromagnetic field radiation is changed with time. However, at present stage, there are several points, which are uncertain, and more detailed research regarding the comparison with theoretical calculation and reconstructed waveforms is required.

Acknowledgement

This work is supported by the Research for the Future Program (Reduction of Electromagnetic Noise Levels), Japan Society for the Promotion of Science.

References

[1] P. F. Wilson, M. T. Ma, "Fields Radiated by Electrostatic Discharges", IEEE Trans. EMC, 33, pp.10-18, Jan. 1991.

[2] S.Ishgami, H. Ida, T. Iwasaki, "Measurements of complex antenna factor by the near field 3-antenna method", IEEE Trans. EMC, 38, pp.424-432, Aug. 1996.

[3] S.Ishgami, T. Iwasaki, "Evaluation of Charge Transition in a Small Gap Discharge", IEICE Trans. Commun., E-79B, 4, pp.715-432, April 1996.

[4] L. Hamada, N. Otonari and T. Iwasaki, "Measurement of electromagnetic fields near a monopole antenna excited by a pulse", IEEE Trans. EMC, 44, pp.72-78, Feb. 2002.

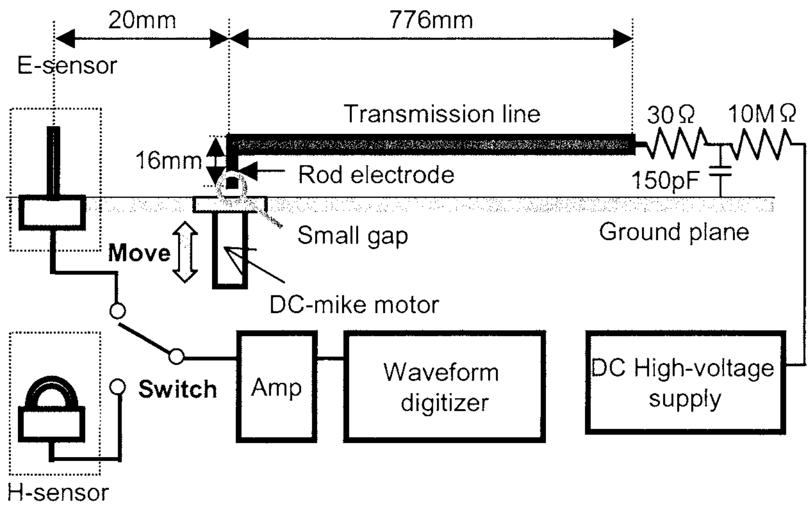

Fig. 1 Experimental setup.

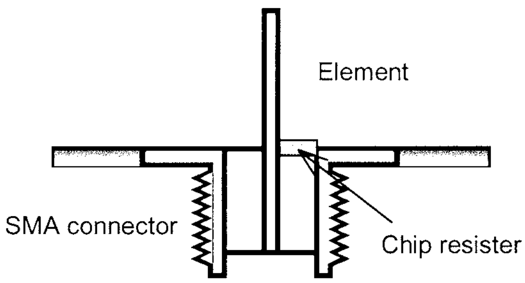

Fig.2 Structure of the electric field sensor.

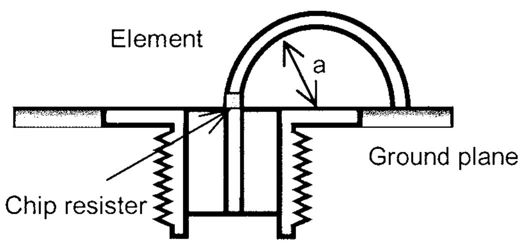

Fig. 3 Structure of the magnetic field sensor.

Table I Dimension and property of the sensor

Diameter of the element	1 mm
Length of the monopole	4mm
Resistance of the chip resistor of the monopole	56 Ω
Diameter of the loop	5 mm
Resistance of the chip resistor of the loop	47 Ω

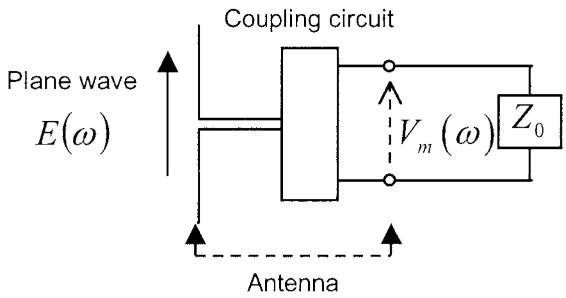

Fig. 4 Complex antenna factor.

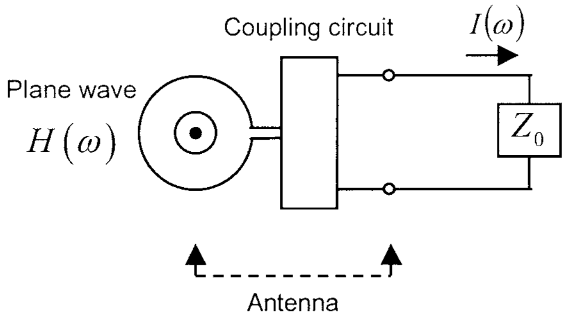

Fig. 5 Magnetic complex antenna factor.

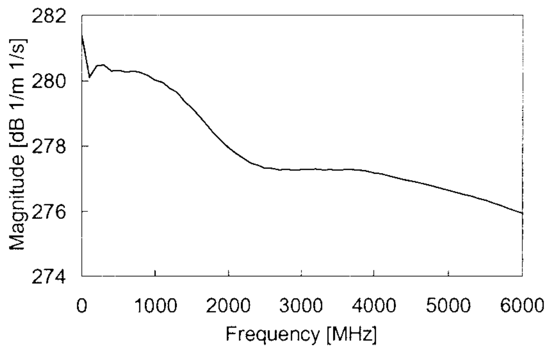

Fig. 6 CAF for the electric field sensor with chip resistor (magnitude).

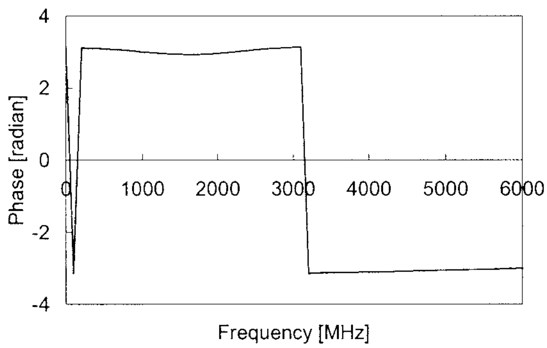

Fig. 7 CAF for the electric field sensor with chip resistor (phase).

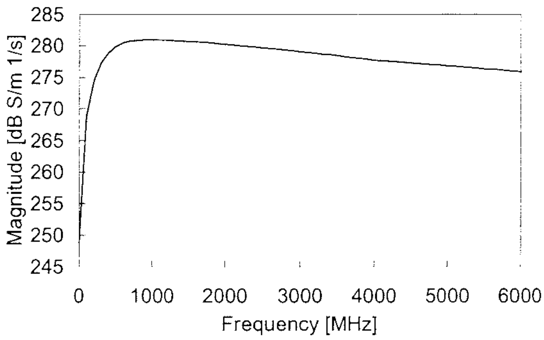

Fig. 8 M-CAF for the magnetic field sensor with chip resistor (magnitude).

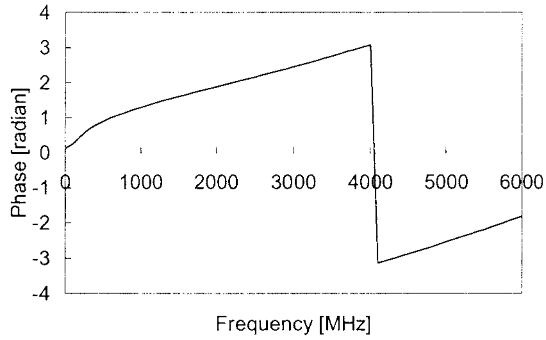

Fig. 9 M-CAF the magnetic field sensor with chip resistor (phase).

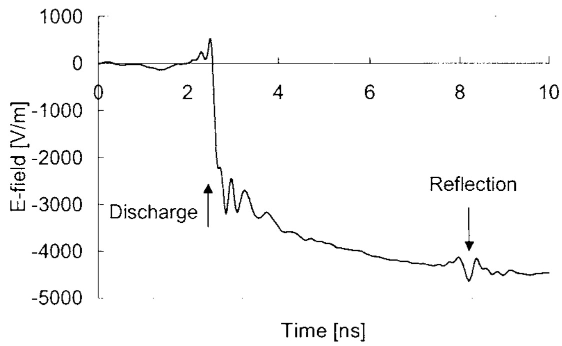

Fig. 10 Reconstructed electric field waveform.

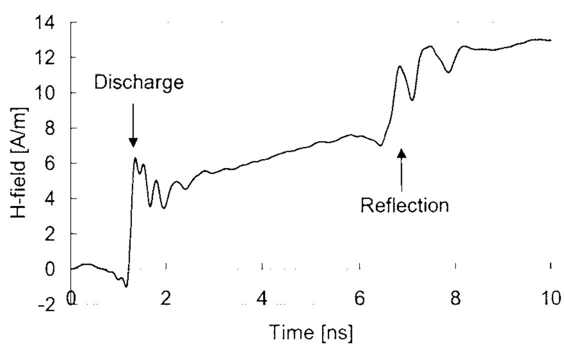

Fig. 11 Reconstructed magnetic field waveform.