6GHz TIME DOMAIN MEASUREMENT OF TRANSITION DURATION DUE TO SMALL GAP DISCHARGE AS ESD

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Abstract Very fast transition duration due to small gap discharge as the low voltage ESD was investigated in time domains. The characteristics of rising time of the transition duration were already cleared in 4.5GHz bandwidth system. In this paper, the measurement system with a tapered coaxial electrode was improved for more high frequency. The insertion loss of a new coaxial electrode was within -3dB in frequency range below about 6GHz. As a consequence of the experiment using the new system, the voltage rise time was shown under 90ps in discharging voltage of below 600V.

Key words : Transition duration, Gap discharge, ESD, Time domains, Distributed constant system

1. Introduction

Very fast transients of electromagnetic field are arisen from gap discharges of ESD 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 EMC. The electromagnetic noise characteristics of gap discharge are gradually becoming clearer [1]-[7].

However, there has been only a little amount of information about voltage waveforms of the transition duration (voltage rising time in positive polarity and voltage falling time in negative polarity) due to a starting of the discharge in very wide band time domain [8]-[11]. Very little is known about the duration of voltage rising time and voltage falling time due to gap discharge at voltages below 1500V. The main purpose of this paper is to clarify the transition duration due to low voltage gap discharge in time domain and frequency domain as the EMI (electromagnetic interference) source.

It is desirable to observe the transition duration due to gap discharge in distributed constant system, because the transients are very rapid. In the first place, a measurement system using the distributed constant system was established to observe the very fast transition duration. It was confirmed that the experimental system enables to measure the high speed voltage transients of about 100ps. The voltage rise time characteristics of the transition duration were already cleared in the 4.5GHz bandwidth system [12][13].

In this paper, the measurement system with a tapered coaxial electrode was improved for high frequency. The insertion loss of new coaxial electrode was within -3dB in frequency range below about 6GHz. As a consequence of the experiment using the new system, the voltage rise time was shown under 90ps in discharging voltage of below 600V. In addition, a relation ship between maximum frequency range of the transients and discharging voltage were cleared in frequency domain using the 4.5GHz system.

2. Improvement of Distributed Coconstant System

Experimental System

The experimental system using distributed constant line system was shown in Fig.1. The system was improved band width from 4.5GHz to about 6GHz. The system consists of a power supply, a tapered coaxial electrode, a directional coupler (HP778D) as coupled transmission lines and semi-rigid coaxial cables (50Ω) as distributed constant lines. The directional coupler was used to observe the transition duration in time domain and frequency domain. When the directional coupler was driven by 35 ps rise time pulse, it had a response of 68 ps rise time in time domain. Fig.2 shows an insertion loss and a coupling factor of the coupler in frequency domain. The coupler shows good characteristics to probe the transition duration of high voltage and high frequency transient.

Fig. 3 shows a longitudinal section view of the tapered coaxial electrode. The electrode consists of
an inner conductor as plane electrode, an outer conductor, a needle electrode and a micro meter head. Each conductor was made of copper. A diameter of the inner conductor is 20.0 mm, an inside diameter of the outer conductor is 46.2 mm, and length of the taper section is 40.0 mm. The taper is a linear physical taper. The characteristic impedance will be constant ($Z_c$) at each point of the tapered coaxial electrode. Impedance matching between the cable and the coaxial electrode was accomplished. The needle electrode was made from a sharpening the inner conductor of the source side semi-rigid coaxial cable. The two needle electrodes have curvature of radius $r=0.1$ mm, and $r=0.5$ mm, respectively. An insertion loss of the electrode measured by a network analyzer (HP8753D, 30kHz-6GHz). Also, a pulse response in time domain was confirmed by TDR (time domain reflectometry) with a sampling oscilloscope (HP54750A, 18GHz). When, a connection between needle and plane electrodes was made by mechanical connection. Fig. 4 shows the insertion loss and the reflection coefficient of the tapered coaxial electrode, (a) is the insertion loss, (b) is the reflection coefficient, the radius of curvature is 0.5 mm needle electrode. The insertion loss was within about -3dB in the frequency range below 6GHz. In figure (b) the reflection coefficient, t1 is a contact point of the needle electrode and the plan electrode, between t1 and t2 is response of the taper section, between t2 and t3 is response of a type N receptacle connector. The impedance of the contact point t1 was little higher than characteristic impedance of the system, while in the taper section, the characteristic impedance was almost same to the system impedance.

In the experiment, the semi-rigid cable with the needle electrode is moved by the micro-meter head. The gap space is reduced gradually. A single-shot waveform of voltage transients at the instance of discharge was observed by a wide band digitizing oscilloscope (Tektronix TDS6604, 6GHz), the frequency spectra were observed by a spectrum analyzer (Agilent Tech. HP8563E, 26.5GHz) in repeated discharge.
3. Measurement of Voltage Waveform of Transition Duration

The wide band digitizing oscilloscope TDS6604 was connected an output of the coupled transmission lines at terminal (3) via a coaxial attenuator of 10 dB or 20 dB (12.4GHz). Voltage waveforms of the transition duration are shown in Fig.5, when the radius of curvature of needle electrode is 0.1 mm. Fig.(a) shows the rising part of transition duration in positive polarity, and fig.(b) is in negative polarity. As above figures are source voltage of 400 V, and below figures are 1090 V, respectively. The horizontal axis is 500 ps/div., and the vertical axis is shown by a conversion value of the coupler and the attenuator, respectively.

In low voltage of 400V, voltage rise sharp to about 150V that the rising time was about from 80ps to 90ps respectively. While in high voltage of 1000V, voltage rise blunt to about 280V and about 200V in positive polarity and in negative polarity. Especially, the voltage waveform was very blunt in negative polarity. The voltage on the distributed constant line at the electrode should rise to half amplitude of the source voltage when connecting the electrode. However, the peak value of the waveforms was lower than the half voltage. This factor of the voltage amplitude is considered to be clear by further experiments in more detail. In this report, the study was limited only to the relative duration time of the voltage transients.

The relationship between the discharging voltage and voltage rise time of the transition duration were confirmed in figure 6. Fig.(a) shows the relationship in positive polarity, and fig.(b) is in negative polarity. As above figures are r=0.5mm radius of curvature of needle, and below figures are 0.1mm, respectively. In low voltage below about 600V, the voltage rise times were very rapid under 90ps.

In changing the source voltage to higher from 400V to 1000V, the voltage rise time was slowed down proportionately from about 80ps to 130ps in positive polarity. While, the voltage rise time was slowed down remarkably from about 80ps to 320ps in negative polarity of the r=0.1 mm needle. It can be considered that the cause of the difference in transition duration influenced the distribution of the electric field in the gap electrode.

4. Conclusion

Very fast transition duration due to the small gap discharge was investigated in time domain.

The measurement system was improved from 4.5GHz to 6GHz. As a consequence of the experiment using the new measurement system, the voltage rise time was shown under 90ps in discharging voltage of below 600V. The voltage rise time was slowed down proportionately from about 80ps to 150ps in positive polarity due to increasing the discharge voltage from 400V to 1000V. While, the voltage rise time was slowed down remarkably from about 80ps to 500ps in negative polarity of the r=0.1 mm needle.

Fig.5 Voltage waveforms of transition duration.
References