Estimate Method of Wideband Transition Duration due to Micro Gap Discharge Using a Transmission Loss of High Performance Semi-Rigid Coaxial Line

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Abstract—**Very fast transients due to micro-gap discharges as low voltage electrostatic discharges (ESDs) were investigated in time domain. We previously developed a 12GHz wideband measurement setup consisting of a distributed constant system, while the observed transients due to micro-gap discharges had very fast rise time of 34 ps or less, which reached the limitation on our system. In this paper, we proposed a method for estimating wideband transients beyond the measurement limit by using the transmission loss of a high performance coaxial transmission line. This method was also validated by estimating an impulsive voltage waveform with rise/fall time of 16ps from the waveform measured through a semi-rigid coaxial cable with a length of 10m.**

I. INTRODUCTION

Very fast transients of electromagnetic field are arisen from gap discharges of ESD and electrical contacts. The transient due to micro 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 very wideband experimental system, because the transients are very rapid. Therefore, the 12GHz band width measurement system using the distributed constant system was established to observe the very fast transition duration. It was confirmed that the voltage and current transition duration has very high speed of about 34 ps [12][13]. However, the

transition duration of 34 ps has already reached to the 12GHz band-limited. It is expect that real transition durations are faster than 34ps rise time.

Therefore, the estimate method of the very wideband transition duration due to micro gap discharge using a high performance semi-rigid cable system was discussed. In this paper, we propose the estimate method with a 15ps rise time impulse waveform of about the 30GHz bandwidth model experimental system.

II. ESTIMATE METHOD USING THE HIGH PERFORMANCE SEMI-RIGID COAXIAL LINE

A. Disposal flow of the estimation

Figure 1 shows a disposal flow chart of the estimate method using the high performance semi-rigid cable system. In the estimation system, $v(t)$ is a rising part waveform of real voltage transients due to occurring by the gap discharge. The $tl(jw)$ is transmission loss of a high performance cable in frequency domain. The $v_0(t)$ is output voltage waveform influence with the transmission loss of the cable. Estimated voltage transition duration is $v'(t)$, it is revised using the transmission loss $tl(jw)$ of a high performance cable.

The other estimate method in past study, the input characteristics of an oscilloscope adopted to correction a measured waveform. However, it is difficult that the correction using the input characteristics of the digital oscilloscope recent model because the input characteristics is a sharp decline at over bandwidth in frequency domain [14].
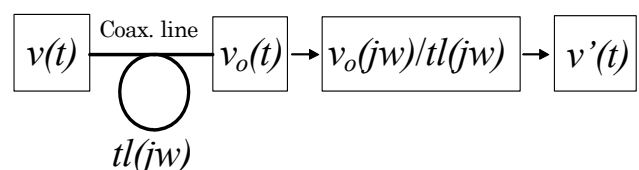

Fig.1 Disposal flow chart of the estimation using the high performance semi-rigid cable system

The proposed method using the high performance cable enables to estimate the transition duration in very wideband fluctuation. The high performance cable has a liner damping coefficient of the transmission loss in frequency domain.

B. The estimate equations

In first, an influence on the transmission loss of high performance cable considers using the four terminal network. Here, V_1 and I_1 is input voltage and current, V_2 and I_2 is output voltage and current in the transmission line, respectively. The A, B, C, and D is the four terminal parameters, S_{11}, S_{12}, S_{21}, and S_{22} are the S parameters. Besides, Z_0 is the terminal impedance of the four terminal network.

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

(1)

where,

$$A = \frac{1}{2}\left\{ S_{12} + \frac{1}{S_{21}}\left(1 + S_{11} - S_{22} - S_{11}S_{22}\right)\right\}$$

$$B = \frac{Z_0}{2}\left\{ -S_{12} + \frac{1}{S_{21}}\left(1 + S_{11} + S_{22} + S_{11}S_{22}\right)\right\}$$

$$C = \frac{1}{2Z_0}\left\{ -S_{12} + \frac{1}{S_{21}}\left(1 - S_{11} - S_{22} + S_{11}S_{22}\right)\right\}$$

$$D = \frac{1}{2}\left\{ S_{12} + \frac{1}{S_{21}}\left(1 - S_{11} + S_{22} - S_{11}S_{22}\right)\right\}$$

(2)

Solving this gives,

$$V_1 = AV_2 + B\frac{V_2}{Z_0}$$

(3)

$$\frac{V_2}{V_1} = \frac{1}{A + \frac{B}{Z_0}}$$

(4)

The estimate voltage of transition duration using the transmission loss of the four terminal network circuit is given by

$$v_1(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\left(A + \frac{B}{Z_0}\right) \cdot V_2(j\omega) \cdot e^{j\omega t} d\omega$$

(5)

where,

$$V_2(j\omega) = \int_{-\infty}^{\infty} v_2(t) \cdot e^{-j\omega t} dt$$

(6)

and

$$A + \frac{B}{Z_0} = \frac{1 + S_{11}}{S_{21}}$$

(7)

Thus

$$v_1(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\left(\frac{1 + S_{11}}{S_{21}}\right) \cdot V_2(j\omega) \cdot e^{j\omega t} d\omega$$

(8)

In above estimate equation, $v_1(t)$ is the estimate voltage of transition duration, $V_2(jw)$ is frequency component of the output voltage $v_2(t)$ calculated from the FFT process. The estimate voltage $v_1(t)$ is calculated from the IFFT process which have a correction the transmission loss of the four terminal network circuit in equation (7). Accordingly, the estimate voltage is given by equation (8).

III. VERIFICATION OF THE ESTIMATE METHOD USING A MODEL EXPERIMENTAL SYSTEM

The estimate method inspects using a model experimental system of very wideband impulse voltage waveform in figure 2. In the model experiments, a very wideband step wave generator (PSPL: 4005, Rise time is 5ps) with a impulse forming network (PSPL: 5206, input is 5ps step wave - output is 15ps impulse wave) used as the very fast voltage transients due to micro gap discharges. The rise time of transition duration of the model waveform is 15 ps, frequency band width is about 30GHz.
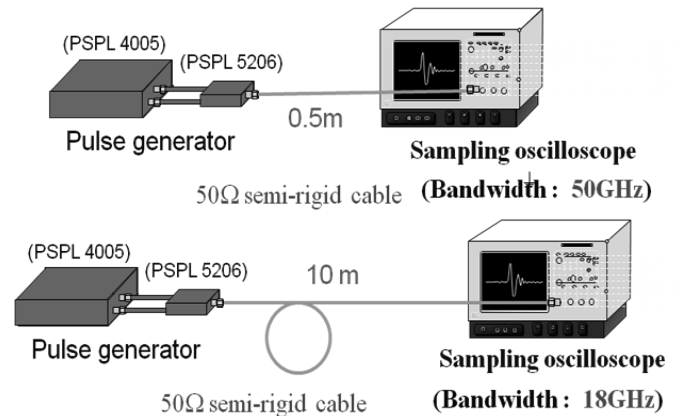

Fig.2 Experimental system using 15 ps impulse waveform of about 30GHz band width.
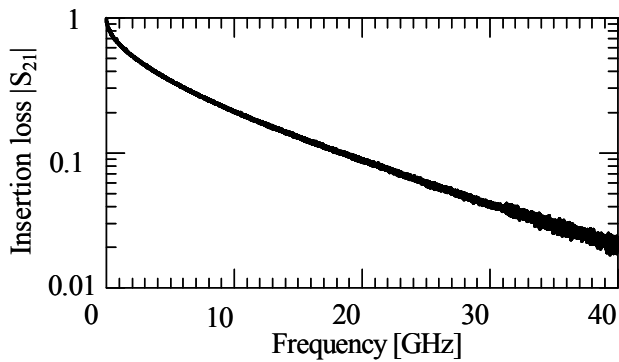
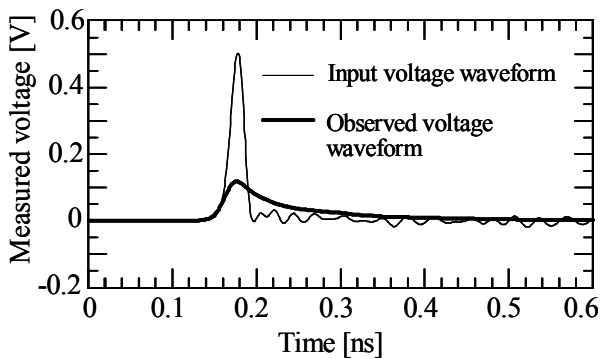Fig.3 Frequency characteristic of the cable as the transmission loss: *tl(jw)* (insertion loss).

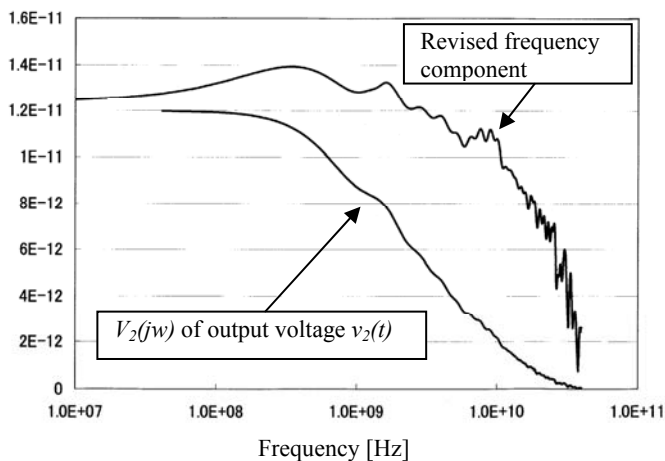Fig.4 Input voltage waveform $v_1(t)$ and output voltage waveform $v_2(t)$ observed with the sampling oscilloscope.

Fig.5 Frequency component $V_2(jw)$ of the output voltage $v_2(t)$ and revised frequency component using the transmission loss *tl(jw)*.

The high performance semi-rigid cable (EZ141/M17) uses to a matter of the transmission loss. Length of the coaxial cable is 10 m, connection system is the 3.5 mm APC system. Figure 3 shows frequency characteristic of the cable as the transmission loss *tl(jw)* (insertion loss). It is confirmed that
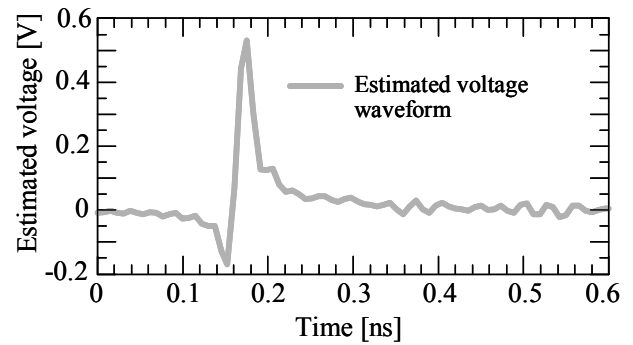

Fig.6 Estimated voltage waveform: *v'(t)*.

the high performance semi-rigid cable has a liner damping coefficient of the transmission loss in frequency range from DC to about 40GHz. The insertion loss of this coaxial cable is about -33 dB at 40GHz.

Figure 4 shows the input voltage waveform $v_1(t)$ and output voltage waveform $v_2(t)$ of the coaxial cable, respectively. These voltage waveforms measured by a sampling oscilloscope (Agilent:86100B) with a 50GHz sampling head (Agilent:83484A). In figure 4, amplitude of input voltage and rise time of the input voltage waveform is 0.5V and about 15.9 ps, on one hand, the amplitude and rise time of the output voltage waveform is about 0.11 V and about 22.6 ps.

Figure 5 shows the frequency component $V_2(jw)$ of the output voltage $v_2(t)$ calculated from equation (6). It was indicated scalar magnitude (absolute value) of frequency component. Also, the revised frequency component using the transmission loss *tl(jw)* of the coaxial cable is shown in a above line in Fig. 5. The difference between an above line and a below line is ingredient of the transmission loss *tl(jw)*. In calculation the IFFT process, a real part and an imaginary part of the frequency component corrected by the transmission loss *tl(jw)* respectively.

Fig. 6 shows the estimated voltage waveform calculated by equation (8). In result of the estimation, the amplitude of voltage and the rise time of transition duration shows about 0.51V and about 15ps. With a little exception of an under-chute, the estimation is approximately good agreement between the input voltage waveform and the estimated voltage waveform.

IV. CONCLUSION

The estimate method of the very wideband transition duration due to micro gap discharge using the transmission loss of high performance semi-rigid coaxial line was examined with a model verification experiments.

As a result, with a little exception of an under-chute, the estimation is approximately good agreement between the input voltage waveform and the estimated voltage waveform. In this study, the rise time of very wideband transition duration was estimated using this method.

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