Transfer impedance of new-type calibration target and reconstruction of injected currents for air discharges from electrostatic discharge generators

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Abstract: We measured in the frequency range from 300 kHz to 6 GHz of the transfer impedance of a commercially available calibration target newly developed for immunity testing against electrostatic discharges (ESDs) being prescribed by the International Electrotechnical Commission. The result showed that the transfer impedance has an almost flat frequency response up to 6 GHz, while resonance phenomena were still observed at frequencies around 2.5 and 5 GHz. With this result, the waveforms of injected currents onto the target were reconstructed from the observed output voltages for air discharges of an ESD generator with a charge voltage of 2 kV.

Keywords: ESD immunity test, new-type calibration target, transfer impedance, ESD generator, air discharge, current reconstruction

Classification: Electromagnetic compatibility (EMC)

References

1 Introduction

The International Electrotechnical Commission (IEC) prescribes the electrostatic discharge (ESD) immunity test of electronic devices in the IEC61000-4-2 [1]. In this immunity testing, the detailed waveform of a discharge current injected onto a calibration target called the Pellegrini target or current detector is specified for contact discharges of an ESD generator. The target is specially designed to have a transfer impedance (rate of an observed sinusoidal voltage to a sinusoidal current injected onto the target) of 1 Ω so that the waveforms of an injected current and the resultant observed output voltage coincide, while its transfer impedance is known to have frequency characteristics and also resonance properties at around 3 GHz [2, 3, 4]. Due to these frequency characteristics, therefore, the observed voltage waveform should not always correspond to an injected current one, whereas it has not well been examined. On the other hand, a calibration target was newly developed, which is said to have an almost flat frequency response up to 6 GHz unlike the Pellegrini target described above [5].

In this study, we measured the transfer impedance of a commercially available new-type calibration target in the frequency range from 300 kHz to 6 GHz with a scattering parameter technique, and thereby reconstructed injected currents from the observed voltages for air discharges of an ESD generator.

2 Calibration target and measurement method

A new-type calibration target has a coaxial structure with a characteristic impedance of $Z_0 = 50 \, \Omega$, which includes a shunt resistor disk with a resistance of $R = 1.03 \, \Omega$ between its inner conductor and outer conductor.

Fig. 1 (a) shows a method for measuring the transfer impedance of a new-type calibration target, which is connected to a commercially available 50-Ω conical coaxial adapter. Measurement of scattering parameters $S_{11}$, $S_{12}$, $S_{21}$, and $S_{22}$ was conducted for the whole part consisting of the adapter and the target with a network analyzer in the frequency range from 300 kHz to 6 GHz.

Fig. 1 (b) shows an equivalent diagram for the target and adapter to derive a transfer impedance of the target from the measured scattering parameters. Also shown in the target of Fig. 1 (b) is an equivalent circuit at low frequencies. Here $Z_0(= 50 \, \Omega)$ is the characteristic impedance, $l$ and $\tau(= 230 \, ps)$ are the length and propagation time of the adapter, respectively. $I(j\omega)$ is a sinusoidal current injected on the target and $V_o(j\omega)$ is the resultant observed
Fig. 1. (a) Setup for measuring scattering parameters of calibration target and (b) its equivalent diagram for adapter and target.

Voltage. Let fundamental parameters for the adapter and the target be $A$, $B$, $C$ and $D$, which can be expressed in terms of the scattering parameters as

$$
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}
= \begin{bmatrix}
\frac{1}{2}
\left\{ (1+S_{11})(1-S_{22}) + S_{12} \right\}
\frac{Z_0}{2}
\left\{ (1+S_{11})(1+S_{22}) - S_{12} \right\}
\frac{1}{2Z_0}
\left\{ (1-S_{11})(1-S_{22}) - S_{12} \right\}
\frac{1}{2}
\left\{ (1-S_{11})(1+S_{22}) + S_{12} \right\}
\end{bmatrix}.
$$

On the other hand, let fundamental parameters for the target itself be $a$, $b$, $c$ and $d$, which are given simply by

$$
\begin{bmatrix}
a & b \\
c & d
\end{bmatrix}
= \begin{bmatrix}
\cos \omega \tau & jZ_0 \sin \omega \tau \\
\frac{jZ_0}{2} \sin \omega \tau & \cos \omega \tau
\end{bmatrix}
^{-1}
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}.
$$

Let $Z_T(j\omega)$ be a transfer impedance of the target, which can be derived from Eqs. (1) and (2) as

$$
Z_T(j\omega) = \frac{V_o(j\omega)}{I(j\omega)} = \frac{1}{c + \frac{d}{Z_0}} = \frac{1}{\left( C + \frac{D}{Z_0} \right) \cos \omega \tau - j \frac{1}{Z_0} \left( A + \frac{B}{Z_0} \sin \omega \tau \right)}.
$$
Fig. 2. Measured frequency characteristics of transfer impedance.

\[
Z_T(j\omega) = \frac{S_{21}e^{j\omega\tau}}{1 - S_{11}e^{j2\omega\tau}} \times Z_0. \tag{3}
\]

At low frequencies, \( \frac{1}{c} = 1/R \) and \( d = 1 \) yield \( Z_T(j\omega) = R \cdot Z_0/(R + Z_0) \approx 1 \Omega \).

Fig. 2 shows frequency characteristics of the transfer impedance, which were calculated from Eq. (3) by using the measured scattering parameters \( S_{11} \) and \( S_{21} \). We found from this figure that the transfer impedance has an absolute value of almost 1 \( \Omega \) at frequencies up to 6 GHz, while resonance phenomena still appear at frequencies around 2.5 and 5 GHz.

### 3 Injected current reconstruction

For validation of the measured transfer impedance, we reconstructed discharge currents injected onto the calibration target for air discharges of a commercially available ESD generator.

Fig. 3 (a) shows a setup for air discharges of the ESD generator. As a ground, an aluminium plate with a side of 1 m was placed horizontally at a height of 67 cm from the floor, and the calibration target was fixed at the centre of the aluminium plate, which was connected through a 50-\( \Omega \) coaxial cable and a 30 dB attenuator to a digital oscilloscope with a bandwidth of 12 GHz and a sampling frequency of 40 GHz. The ESD generator was first set above the target and then approached the target at a constant speed. Then the current \( i(t) \) injected onto the target through a spark discharge can be calculated from

\[
i(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} v_0(\tau) Z_T(j\omega) e^{j\omega(t-\tau)} d\tau d\omega, \tag{4}
\]

where \( v_0(t) \) is the observed voltage. It should be natural that \( i(t) = v_o(t) \) when \( Z_T(j\omega) = 1 + j0 \Omega \).

Left and right figures of Fig. 3 (b) show the reconstructed currents \( i(t) \) from Eq. (4) together with the observed voltages \( v_0(t) \) for air discharges of the ESD generator with slow approach (2 cm/s) and fast approach (20 cm/s), respectively. The lower figures show enlargements of the rising waveforms.
Fig. 3. (a) Experimental setup for air discharges of ESD generator and (b) observed target voltages and reconstructed currents injected on the target.

of the reconstructed current and observed voltage. We found that the reconstructed current for slow approach agrees well with the observed voltage because of its gentle rise time of almost 1 ns, while the reconstructed current for fast approach has a slightly small peak and a bit gentle rise time in comparison with those of the observed voltage despite the resonance characteristics of the transfer impedance at frequencies over 1 GHz. This can qualitatively be explained in the following way. The injected current for fast approach should have a rapid rise time of around 90 ps so that the current contains the frequency components with a cut-off frequency of almost 4 GHz. As shown in Fig. 2, the resistive components of $Z_T(j\omega)$ have negative polarity in the frequency range from 1 GHz to 4 GHz, which may have resulted in the
smaller peak and gentle rise time of the reconstructed current from Eq. (4).

4 Conclusion

We measured the transfer impedance of a commercially available new-type calibration target in the frequency range from 300 kHz to 6 GHz. By using this result, we reconstructed the waveforms of discharge currents injected onto the target from their observed output voltages for air discharges of an ESD generator. As a result, we found that the transfer impedance has an absolute value of almost $1+j0 \Omega$ up to 6 GHz, while resonance phenomena still appear at frequencies around 2.5 and 5 GHz. This result demonstrated that the reconstructed discharge currents agree well with the observed voltages for the air discharge with slow approach of an ESD generator with a charge voltage of 2 kV, producing the current with a rise time of almost 1 ns, while the reconstructed current has a slightly small first peak and gentle rising part compared to those of the observed voltage for the air discharge with fast approach, which gives the current with a rapid rise time shorter than a hundred picoseconds.

A future subject is to investigate the variations in reconstructed currents injected onto the calibration target for air discharges from an ESD generator with different charge voltages.