A NEWLY DEVELOPED CALIBRATION SYSTEM FOR ESD SIMULATORS

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INTRODUCTION

ESD simulators are the main equipment to perform ESD immunity test. IEC 61000-4-2 stipulates the specifications of ESD simulators，such as the discharge current waveform, parameters and the output voltage. In order to ensure the quality of the ESD test, a periodical calibration for ESD simulators is necessary. A new calibration system for ESD simulators as per IEC 61000-4-2 is developed. It consists of two subsystems: one is for discharge current measurement, and the other is for output voltage measurement.

CALIBRATION FOR DISCHARGE CURRENT WAVEFORM

The discharge current waveform calibration subsystem consists of a discharge target, a Faraday shield cage, a 20dB attenuator, a low loss cable, a digital storage oscilloscope with 5GHz bandwidth and 20GS/s sample rate, as shown in Fig. 1.

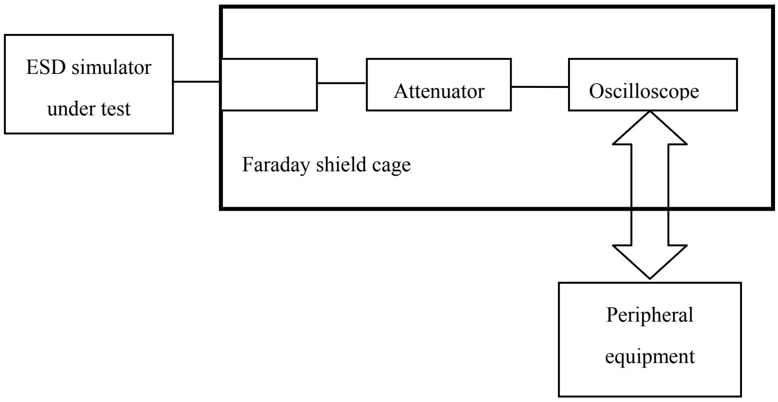

Fig.1. *Set up for current waveform calibration subsystem*

The ESD current generated from the ESD simulator under test is transformed to a voltage signal by the target. This voltage signal is reduced in amplitude by the attenuator, and then sent to the oscilloscope. The attenuated voltage waveform can be captured on the oscilloscope, and the rise time, the amplitude of the first peak, the amplitude at the time of 30ns and 60ns can be read respectively.

When the rise time of the measurement system is short enough, the rise time of the voltage waveform is that of the current waveform.

The amplitude of the ESD current is calculated by

$$I = 10^{\frac{[A]}{20}} KE \qquad (1)$$

where，I is the current amplitude of the ESD, in A; $[A]$ is attenuation of the attenuator and the transmission system, in dB; K is the transform coefficient of the target，in Ω^{-1}; and E is the voltage measured by the oscilloscope, in V.

• **The Target**

IEC 61000-4-2 recommends a structure of the target and the parameters of resistors, but does not specify its specifications. The calibration of the target is a key to current waveform measurement.

Being a current sample device, the target is used for transforming the discharge current waveform to the voltage waveform. The DC equivalent circuit of the discharge target is shown in Fig. 2.

Where, I_X is the input discharge current of the target, E_X is the output voltage. R_I is the input resistor of the target, it absorbs the most discharge current; R_V is the matched resistor. Output resistance of the target can achieve 50 ohms by selecting a proper resistance of the R_V. R_0 is the load resistor, also the input resistor of the voltage measurement instrument. The most important characteristics of a target are its transform coefficient, frequency response and rise time.

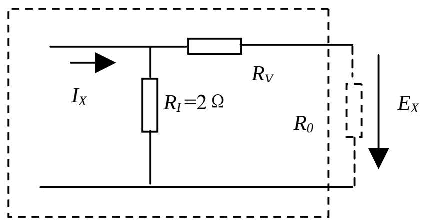

Fig. 2. *DC equivalent circuit of the target*

The current/voltage transform coefficient K is calculated by

$$K = \frac{I_X}{E_X} = \frac{R_I + R_V + R_0}{R_I R_0} \qquad (2)$$

The transform coefficient K is measured easily under DC condition and needs to be corrected as per the practical value while used in Eq. (1). The frequency response of the target can also affect the current amplitude measurement since the ESD current pulse has a wide frequency spectrum. It is difficult for measuring the frequency response of the target to connect the target to a coaxial measurement system. A kind of special matched adapter is developed to connect the target to a coaxial measurement system. The frequency response of the matched adapters can be measured by connecting two adapters in face to face. Frequency response is measured using a network analyzer and a spectrum analyzer respectively, and the results are almost identical. The measurement results indicate that the frequency response of the adapters is satisfactory. The 3 dB bandwidth can achieve several GHz.

After the adapter is calibrated, the frequency performance of the target can be measured with a microwave network analyzer. The measurement result shows that its bandwidth is over 2000MHz, verifying that the target bandwidth meets the requirement of IEC 61000-4-2. And a pulser with known fast rise time is used to measure the rise time of the target/cable/attenuator/scope chain, showing the rise time of which is 170ps that causes the uncertainty of approximate 6%(k=2) for 700ps rise time measurement.

• **The Attenuator**

A 20 dB attenuator is selected, thus the input voltage can be reduced ten times. It is necessary to calibrate the attenuator due to the difference between the nominal attenuation and the actual one. The frequency response of the attenuator also affects the amplitude measurement. The upper limit frequency of the attenuator used in the system is 18 GHz. It must also endure the pulse peak power.

• **Oscilloscope**

Oscilloscope is the very important equipment for current waveform measurement. Wide bandwidth and high sample rate can improve measurement accuracy.

Suggest that the ESD current waveform be a sharp pointed impulse, both the rise and fall edges are the beelines. See Fig. 3.

It is possible that the peak point is not captured due to the limited sample rate of the oscilloscope. This will lead to an error for peak amplitude measurement. Suggest the sample rate be S_a, the time interval of the adjacent sample point is T, thus T=1/S_a.

When the peak point is at the middle of the adjacent sample points, the error of the peak amplitude measurement is the maximum. Considering the current pulse rise time (t_r) is the time interval from the 10% to 90% of the peak amplitude (E_p), the maximum error should be

$$\Delta_{max}=AC=(EB/DB)AB=(0.4T/t_r)E_p$$

Or expressed by the relative error

$$\gamma_{max}=(0.4T/t_r)\times 100\%$$

The error that the oscilloscope does not capture peak point abides by rectangle probability distributing in the range of 0 ~ γ_{max}.

Suggest the rise and the fall rates of the impulse be equal the standard uncertainty that the oscilloscope does not capture peak point is

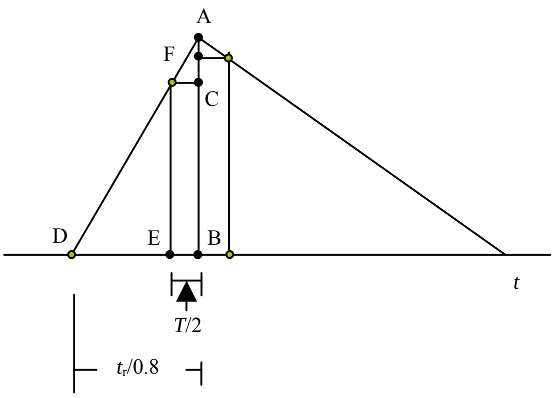

Fig.3. *Peak amplitude measurement error analysis*

$$u_{Sa}=\frac{\gamma_{\max}}{2\sqrt{3}}$$

Since the rise time is much shorter that the fall time of the pulse, the actual uncertainty caused by the limited sample rate is much less than that estimated above.

• **Cable**

High frequency loss of the cable will affect the voltage amplitude measurement . The loss of the cable includes skin effect loss and the dielectric loss. The cable characteristic is measured by a network analyzer. A 40cm low loss coaxial semi-rigid cable with 50 ohm characteristic impedance is used in this system.

DEVELOPMENT OF THE ELECTROSTATIC VOLTAGEMETER

The output voltage measurement subsystem is a self-developed electrostatic voltmeter with accuracy ±0.2% and input impedance higher than 40Gohm.

The electrostatic voltmeter consists of input divider, input circuit, range converter, analog to digital converter, display driver and the display circuit. Comparing with the ordinary direct circuit digital voltmeter, the keys are the high impedance high voltage divider and the isolation structure. The key of the high voltage divider design is to achieve higher measurement accuracy in the condition of high impedance.

A series of measures are taken to obtain favorable performances, such as trying a new kind of materials to improve the resistance ratio of the synthesized film resistors, designing reasonable groove structure and increasing its length, spraying the serum on the same floor to obtain consistency of the resistance parameters.

Calibration for this electrostatic voltmeter is performed. The measurement range is up to ±40kV, the accuracy is better than ±0.2% of readings, the input impedance is higher than 40Gohm, the display is 4 1/2 digits.

DESIGN OF THE FARADAY CAGE

A new kind of Faraday cage with temperature controlled and unsymmetrical structure is designed to admit the target/attenuator/cable/oscilloscope measurement chain, to avoid being disturbed by the discharge current emission. Some interface adapters, such as for monitor, mouse, keyboard and parallel ports are fixed on the rear panel of the cage. The external monitor, mouse, keyboard and printer can be connected to the relative output ports of the oscilloscope inside the cage via these filtered adapters respectively. Thus, the measurement course of the discharge current can be viewed and controlled by the above-mentioned peripheral equipment. With a simple calculation program being developed, the rise time, first peak current, currents at 30ns and 60ns of the waveform are calculated automatically, and the calibration certificates can be generated easily. The calibration certificate can also be sent to the printer out of the cage if necessary.

UNCERTAINTY EVALUATION

The uncertainty of the calibration result is of importance to indicate the reliability of the measurement. The calibration uncertainties for measuring peak amplitude, rise time of the ESD current and output voltage are evaluated.

For peak current measurement, based on fig. 1 and Eq. (1), the main uncertainty sources are from the target, attenuator, cable and oscilloscope.

Table I gives an example for an uncertainty budget for the peak current measurement.

TABLE I AN EXAMPLE FOR AN UNCERTAINTY BUDGET FOR PEAK CURRENT MEASUREMENT

Uncertainty Contribution	Probability distribution	Standard Uncertainty (%)
Transform coefficient measurement of target	Gaussian	0.1
Voltage measurement of oscilloscope	Rectangular	0.87
Amplitude flatness up to 2GHz	Gaussian	0.75
Error of the peak amplitude measurement due to the limited sample rate	Rectangular	0.84
RF loss measurement of the cable/attenuator chain	Gaussian	1.8
Mismatch between target/attenuator/cable and oscilloscope	U-shaped	0.23
System repeatability	Rectangular	1.4
Combined standard uncertainty		2.7
Expanded uncertainty (*k*=2)		5.4

The transform coefficient of target is calibrated under the DC condition, and the actual value will be used in the ESD current measurement, thus this uncertainty is mainly from the calibration of the R_I, R_V and R_0 shown in Eq. (2).

The attenuation of the cable/attenuator chain is calibrated, and the actual value will be used in the ESD current measurement. The uncertainty is from the calibration uncertainty of the attenuator/cable chain and its frequency response.

In the case of the same impedance, the mismatch uncertainty of the voltage measurement is the 1/2 of that of the power measurement, namely

$$u_M = \frac{1}{\sqrt{2}} |\Gamma_A| |\Gamma_{Scope}|$$

Where Γ_A and Γ_{scope} are the reflection coefficients of chain output and the oscilloscope input respectively. The calibrated VSWR of output port of the target/attenuator/cable chain is 1.15 up to 1GHz. And VSWR of the oscilloscope input port is estimated to be 1.2.

COMPARISON

After the project is fulfilled, the comparison between 514th Institute and China National Institute of Metrology (NIM) is made to verify the performance of the newly developed ESD simulator calibration

system. An ESD simulator is used as a transfer DUT, to be calibrated at the 514th Institute laboratory and NIM respectively. Table II gives the calibration results of the peak current and rise time.
From the Table, the comparison results meet

$$E_n = \frac{|R_{514} - R_{NIM}|}{\sqrt{U_{514}{}^2 + U_{NIM}{}^2}} \le 1$$

where, R_{514} is the calibration result by 514th Institute; R_{NIM} is the calibration result by NIM; U_{514} *is the* expanded uncertainty of 514th Institute; U_{NIM} is the expanded uncertainty of NIM.

TABLE II COMPARISON OF PEAK CURRENT AND RISE TIME CALIBRATIONS

Output Voltage (kV)	Peak Current Calibration (A)		Rise Time Calibration (ns)	
	514	NIM	514	NIM
2	7.13	7.09	0.82	0.84
4	14.8	14.62	0.83	0.85
6	22.8	22.39	0.82	0.87
8	30.5	30.25	0.86	0.84
-2	-7.21	-7.07	0.84	0.87
-4	-15.1	-14.99	0.88	0.86
-6	-23.4	-22.48	0.86	0.85
-8	-30.2	-29.52	0.85	0.86

CONCLUSION

A calibration system for electrostatic discharge（ESD） simulators newly developed by the 514th Institute as per IEC61000-4-2 is introduced. The discharge current and output voltage generated from ESD simulators can be calibrated by this system accurately and expediently. The rise time, first peak current, currents at 30ns and 60ns of the waveform are calculated automatically, and the calibration certificates can be generated easily.

A new kind of special matched adapter is developed to connect the target to a coaxial measurement system. This makes it possible to calibrate the frequency response and rise time of the target. With the Eq. (1) the actual calibration data of the target, attenuator and the cable being used in the calculation, the better calibration uncertainty of the ESD current is achieved.

The comparison between the 514th Institute and NIM is made to verify the performance of the newly developed ESD simulator calibration system, and achieves a satisfied result.