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An Approach to the Better Understanding of the Experimental Setup for the Verification of the ESD Generators

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Abstract: The International Standard IEC 61000-4-2 for electrostatic discharge defines the procedure and the equipment for the verification of the electrostatic discharge generators. The Standard defines that for the verification the Pellegrini target, which is used as a current transducer, must be mounted on a grounded metal plane. This paper examines the aberrations on the current waveform for different mountings of the Pellegrini target. Electrostatic discharges have been conducted for both the contact and the air discharge mode. Useful conclusions for the current's waveform parameters as the maximum current, the rise time and the current's value at 30 and 60 ns are presented. Also, useful comments on the construction of the ESD generators in the future revision of the Standard are mentioned.

INTRODUCTION

Electrostatic discharge (ESD) is very common in our lives. The human body can be charged up to a potential of 10-15 kV by walking on a carpet due to the triboelectric phenomenon. When the discharge takes place the discharge current may come up to a few Amperes. This makes clear that the electrostatic discharge may be destructive for electronic or integrated circuits, which are very sensitive to these currents although the ESD phenomenon lasts a few hundred nanoseconds. Therefore, the IEC (International Electrotechnical Committee) edited the Standard 61000-4-2 [1] in order to define the procedure, which must be followed for the tests on electrical or electronic equipment against electrostatic discharges.

This Standard not only does define the procedure for carrying out the tests on Equipment under Test (EUT), but also defines the necessary equipment and the verification procedure of the ESD generators. The equipment for the verification of the ESD generators in order to know if they work satisfactory and in accordance to the limits that have been decided is: an oscilloscope with bandwidth of at least 1GHz, a current transducer (Pellegrini target), HF coaxial cables and attenuators.

A considerable amount of effort has been made in order the ESD current waveforms to be studied and it has been shown that the amplitudes and the rise times vary with the charging voltages, approach speeds, electrode types, the relative arc length and humidity [2]. In [3], [4] the current waveforms and the produced electromagnetic fields have been investigated taking into consideration correlated parameters to the ESD event, in order to imrove the repeatability of the ESD generators.

ELECTROSTATIC DISCHARGE CURRENT

The IEC 61000-4-2 [1] relates to equipment, systems, sub-systems and peripherals, which may be involved in static electricity discharges owing to environmental and installation conditions, such as low relative humidity, use of low conductivity carpets, etc.
According to the IEC 61000-4-2 the electrostatic discharges can occur either as contact discharges or as air discharges. The application of contact discharges is the preferred test method and air discharges shall be used in cases, where contact discharges cannot be applied. The range of the test level voltages for the contact discharges is 2 to 8 kV and for the air discharges is 2 to 15 kV. It must be underlined that for the verification of the ESD generators the discharges are contact discharges and not air discharges. The ESD generator must produce a HBM (Human Body Model) pulse [5] as it is shown in Fig.1.

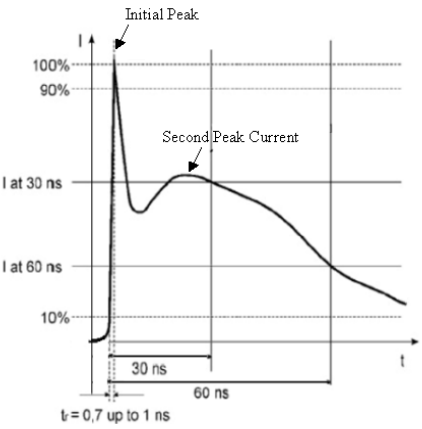

Fig.1: Typical waveform of the output current of the ESD generator [1].

The pulse of Fig.1 is divided into two parts: A first peak called "Initial Peak", caused by a discharge of the hand (where there is the maximum current I_{max}) and a second peak, which is caused by a discharge of the body. The rise time of the Initial Peak is between 0.7 ns and 1 ns and its amplitude depends on the charging voltage of the ESD simulator.

According to the specifications of the Standard for the verification of the ESD generators there are 4 parameters whose values have to be within specified limits. These parameters are: the rise time (t_r), the maximum discharge current (I_{max}), the current at 30 and 60 ns, I_{30} and I_{60} respectively. As it is shown in Fig.1 these two current values are calculated for a time period of 30 and 60 ns respectively starting from the time point, when the current equals to 10% of the maximum current. The limits of these parameters are shown in Table I and are valid for contact discharges only.

Table I: Values for the four parameters of the dicharge current according to IEC 61000-4-2 [1]

V (kV)	I_{max} (A)	t_r (ns)	I_{30} (A)	I_{60} (A)
2	6.75-8.25	0.7-1	2.8-5.2	1.4-2.6
4	13.5-16.5	0.7-1	5.6-10.4	2.8-5.2
6	20.25-24.75	0.7-1	8.4-15.6	4.2-7.8
8	27-33	0.7-1	11.2-20.8	5.6-10.4

MEASUREMENT SETUP

Fig.2 shows the measurement set-up. The experimental equipment used was the Schaffner's NSG-438 ESD generator producing both positive and negative discharges, the Schaffner's resistive load (Pellegrini target) model MD 101, HF coaxial cables, attenuators and a Tektronix oscilloscope model TDS 7254B, whose bandwidth ranged from dc to 2.5 GHz and the near field probes HZ-11 of Rohde & Schwarz. The resistive load was designed to measure discharge currents by ESD events on the target area and its bandwidth is ranged from dc to above 1 GHz.

In order the measurement set-up to be unaffected by surrounding systems, the experiment was conducted in an anechoic chamber, and the cables were set away from the discharge gap. The generator's capacitance was charged with both positive and negative polarity, and the charging voltages were set to ±2 kV. Also, the ESD generator was used in both contact and air discharge mode for this charging voltage. The temperature and relative humidity were measured and found 23±1°C and 45±3 %, respectively.

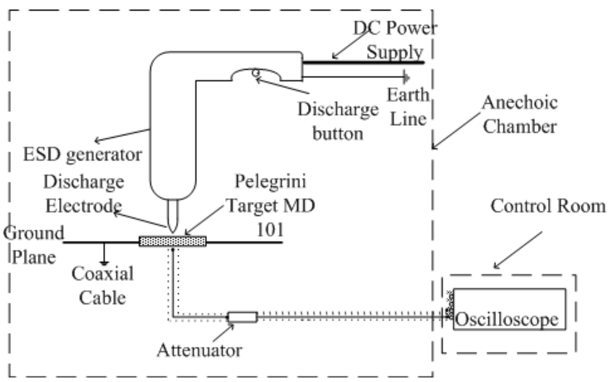

Fig.2: ESD current measurement set-up.

The Pellegrini target was mounted in four different planes. The first was a grounded metal plane with dimensions 1.5 m × 1.5 m and the second was a grounded metal plane with dimensions 1 m × 1 m. The third was the wall of the anechoic chamber with dimensions 36 cm × 36 cm and the fourth was a plane made of insulating material. These different planes can be seen in Figs. 3-6.

Fig.3: Target mounted on the horizontal metal plane with dimensions 1.5m x 1.5m (case 1).

Fig.4: Target mounted on the horizontal metal plane with dimensions 1m x 1m (case 2).

Fig.5: Target mounted vertically on the wall of the anechoic chamber (case 3).

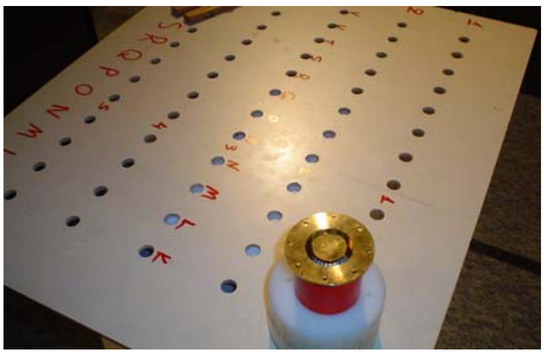

Fig.6: Target on the insulating material (case 4).

CURRENT'S RECONSTRUCTION

The equivalent circuit of the measurement system at DC analysis is illustrated in Fig.7 and it includes the ESD generator, the current transducer and the oscilloscope [6]. In this figure R_L, R_b and Z_0 are the load resistance of the current transducer (CT), the backward matching resistance of the CT and the nominal input impedance (50 Ohms) of the measurement system including the oscilloscope, respectively.

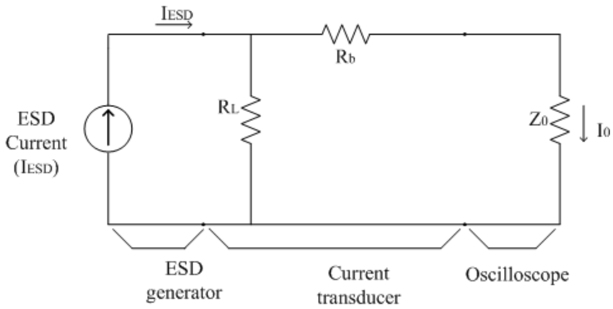

Fig.7: The equivalent circuit of the ESD generator at DC analysis.

The discharge current is defined by the following equations:

$$I_{ESD} = \frac{C \cdot V_R}{Z_0} \quad (1)$$

$$C = C_{CT} \cdot C_A \quad (2)$$

$$C_{CT} = \frac{I_{ESD}}{I_0} = \frac{R_L + R_b + Z_0}{R_L} \quad (3)$$

where I_{ESD} is the amplitude of the discharge current, V_R is the voltage measured by the oscilloscope due to the output current I_0. C is a current conversion factor; C_{CT} and C_A are the conversion factors of the CT and the attenuator, respectively. Equations from 1 to 3 are approximate with assuming matching on the output i.e. exactly 50 Ohms. Sroka in [7] presented a more detailed current reconstruction.

The values of R_L and R_b can be found by measuring the DC resistance of the Pellegrini target. Although available data of the target could be used, this was avoided in order the measurement results to be more accurate. The DC load resistance of the target (R_L) is the resistance between the inner electrode (disc) and the outer electrode of the CT. R_L was found 2.005 Ohms. The DC backward matching resistance of the CT (R_b) is the resistance between the input and the output of the inner electrode of the target. It was found that R_b was 48.246 Ohms. These two values (R_L and R_b) were calculated by taking the average value of 20 measurements in order to minimize the measurement uncertainty. Taking all the above into consideration the voltage reading of 1V at the oscilloscope corresponds to the discharge current of approximately 10A. The attenuator was of 20 dB, i.e. C_A=10.

MEASUREMENT RESULTS

The oscilloscope used for the measurement of the discharge current, which lasts a few hundreds nanoseconds. In Figs. 8-11 a comparison of the ESD currents for different mountings of the Pellegrini target and for both contact and air discharges at ±2 kV.

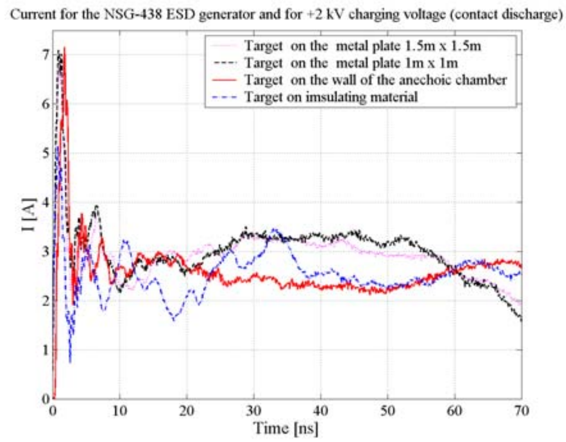

Fig.8: Comparison of the ESD current for +2 kV charging voltage (contact discharge).

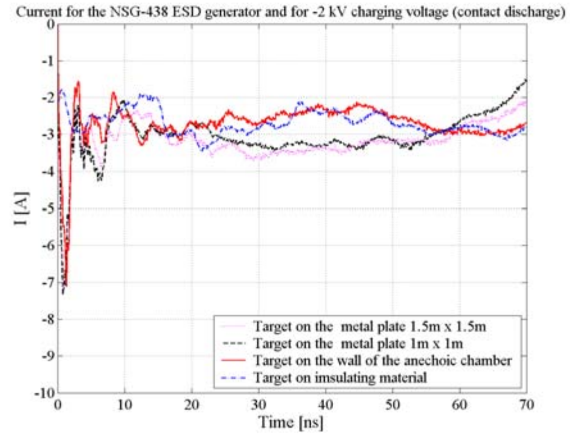

Fig.9: Comparison of the ESD current for -2 kV charging voltage (contact discharge).

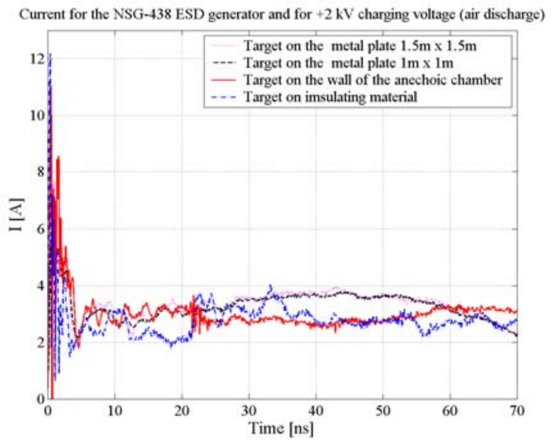

Fig.10: Comparison of the ESD current for +2 kV charging voltage (air discharge).

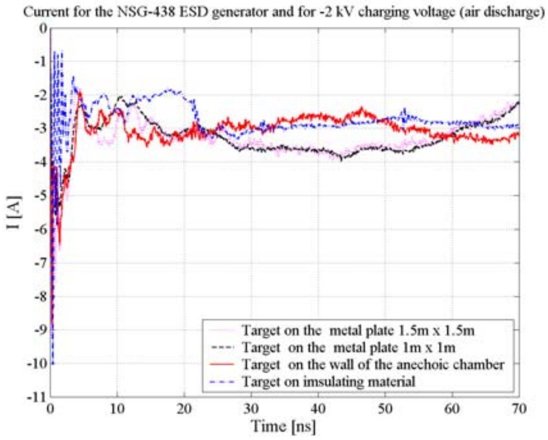

Fig.11: Comparison of the ESD current for -2 kV charging voltage (air discharge).

Both contact and air discharges were conducted many times for the same voltage level and for the same target mounting. The average values of the parameters of these measurements were calculated. Synoptically, these values (t_r, I_{max}, I_{30} and I_{60}) are shown in tables II -V.

Table II: Values for the four parameters for +2 kV charging voltage (contact discharges)

Contact discharges at +2 kV				
	t_r	I_{max}	I_{30}	I_{60}
Case 1	0.73	6.96	3.25	2.48
Pass	YES	YES	YES	YES
Case 2	0.71	7.09	3.30	2.59
Pass	YES	YES	YES	YES
Case 3	1.19	7.16	2.54	2.61
Pass	NO	YES	NO	YES
Case 4	0.68	5.13	2.80	2.65
Pass	NO	NO	YES	NO

Table III: Values for the four parameters for -2 kV charging voltage (contact discharges)

Contact discharges at -2 kV				
	t_r	I_{max}	I_{30}	I_{60}
Case 1	0.71	-7.55	-3.56	-2.55
Pass	YES	YES	YES	YES
Case 2	0.70	-7.30	-3.25	-2.59
Pass	YES	YES	YES	YES
Case 3	1.20	-7.06	-2.68	-2.85
Pass	NO	YES	NO	NO
Case 4	1.89	-3.01	-2.90	-2.90
Pass	NO	NO	YES	NO

Table IV: Values for the four parameters for +2 kV charging voltage (air discharges)

Air discharges at +2 kV				
	t_r	I_{max}	I_{30}	I_{60}
Case 1	0.39	10.1	3.61	3.16
Case 2	0.44	5.66	3.49	3.13
Case 3	0.33	11.04	2.58	3.26
Case 4	0.30	12.16	3.01	2.80

Table V: Values for the four parameters for -2 kV charging voltage (air discharges)

Air discharges at -2 kV				
	t_r	I_{max}	I_{30}	I_{60}
Case 1	0.22	-9.25	-3.44	-3.14
Case 2	0.39	-5.59	-3.62	-3.24
Case 3	0.21	-8.80	-3.02	-3.32
Case 4	0.37	-10.02	-3.10	-2.81

The differences between the four cases can be easily seen. In air discharges it was observed that there were differences in I_{max} due to the different arc lengths. Whether the measured values are in accordance to the Standard or not can be easily seen in tables II and III and only for the contact discharges. If it is accordance to the Standard it is marked as "YES" otherwise as "NO". This happens because in contact discharges the discharge phenomenon is reproducible and the current waveforms can be compared. On the contrary in air discharges this comparison is very difficult to be made due to the fact that there are different arc lengths.

WHAT THE NEXT REVISION OF THE STANDARD SHOULD INCLUDE

As it was described previously the discharge current depends on the different plate or material, where the current transducer is mounted on. It must be mentioned that though the discharge current can be within the limits that are defined by the Standard, the ESD generators could give different results at the same EUT. The measurement of the magnetic field proved that each generator was producing a different field. Such a measurement is illustrated in Fig.12, proving that two different ESD generators (NSG-433 and NSG-438 of Schaffner) produce different magnetic fields at a distance of 10 cm from the discharge point (contact discharge) and for +2kV charging voltage. That is the reason for different induced voltages to be produced, and the same EUT to pass the test with one ESD generator and to fail with another. This is why the next revision of the Standard should define limits for the transient fields produced by the ESD generators.

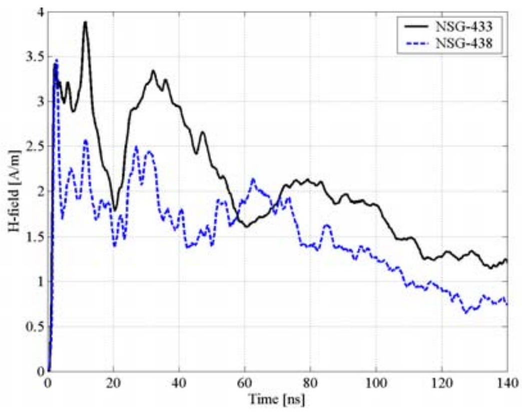

Fig.12: Comparison of the H-field produced by two different ESD generators at 10 cm from the discharge point (charging voltage= +2 kV).

CONCLUSIONS

It is obvious that useful remarks can derive from the measurement results. A very crucial point for the comparison of the different cases is that the current's waveforms can be compared only for contact discharges. This is the reason why the verification of the ESD generators is done according to the existing Standard in the contact discharge mode.

Keeping these in mind the following conclusions derive for the contact discharges at ±2 kV. First of all the more conductive the metal plane is (larger conductive surface), where the target is mounted the smaller the rise time, although in cases 1 and 2 it is approximately the same. Also, the larger is the surface of the metal plane the lower is the value of I_{max}. It can be observed that for the three metallic grounded planes the I_{max} values are similar, but when the target is on the insulating material the maximum current is very lower. As far as the currents I_{30} and I_{60} concerns there is a small deviation between the four different cases. At this point it must be said that according to [8] the current I_{60} is very sensitive to the ground cable layout, which is a reason explaining the similar value for the four different cases.

Also, from Tables I and II it is obvious that the cases, where the values of these four parameters are in the limits defined by the Standard are cases 1 and 2 with the target mounted on the metal plane with dimensions 1.5 m x 1.5 m and 1 m x 1 m, respectively. This proves that the values of the four parameters are within the limits not only for the metal plate of 1.5 m x 1.5 m, as the Standard defines, but also for the plate of 1 m x 1 m. Consequently, the Standard can be more flexible for the measurement setup for the verification. Similar conclusions can derive for the other voltage levels defined by the Standard (±4 kV, ±8 kV), but are not presented here due to the limited space of this paper.

For the air discharges it can be seen that similar conclusions with the contact discharges can be derived. The more conductive is the plane the greater are the values of I_{max}. Also the currents I_{30} and I_{60} have a small deviation between the four different cases.

In both contact and air discharges it can be observed that the greater the metallic surface the less the ringing on the current's waveform.

A future work should include current's measurement, when the target is mounted on different materials and in various positions, in order useful conclusions to be derived. In this work it was proved that the current is different, depending on where the target is mounted. Therefore a further investigation should include measurements of the radiating electromagnetic field for various planes in dimensions, materials and position. There is a need for these measurements, because in the present literature the experiments for the measurement of the electromagnetic field have been carried out only for the target mounted on metal planes. Furthermore a future revision of the present Standard for the limit definition of the produced electromagnetic filed is necessary. The dependency of the magnetic field from the discharge current should be investigated. Measurements with the target mounted on an insulating material would be closer to the real discharge conditions of the ESD generators, since the metal planes alter the electromagnetic field.

ACKNOWLEDGMENTS

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