MEASUREMENT OF THE MAGNETIC FIELD RADIATING BY ELECTROSTATIC DISCHARGES USING THE STANDARD ESD GENERATORS

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Abstract: This paper presents measurements of the magnetic field (H-field) generated by air electrostatic discharges, a few centimeters away from the discharge point. The aim of this paper is to investigate the radiating magnetic fields produced by four different generators of electrostatic discharges, since the European Standard EN 61000-4-2 for the electrostatic discharges doesn't define anything about the produced electromagnetic fields. A comparison of these generators is made and useful conclusions are derived.

Keywords: Electrostatic Discharge (ESD), European Standard EN 61000-4-2, ESD generators, magnetic field, field probes.

1 INTRODUCTION

The Electrostatic Discharge (ESD) is defined as the sudden transfer of charge between objects at different electrostatic potentials [1, 2]. Electrostatic charge is created whenever two different materials come into contact and are then separated. Creating electrostatic charge by contact and separation of materials is known as "triboelectric effect". The charge is transferred between objects normally via a spark, when the potential across the narrowing air gap is high enough to cause breakdown [3] and it is obvious that ESD is a transient overvoltage pulse with a steep rising edge, a high current amplitude but low energy content.
A considerable amount of effort has been made to study the current waveforms deriving from ESD and it has been proven that they are affected by various factors. David Pommerenke [4, 5] found that the current waveform is depending on the relative arc length, the charging voltage and the geometric characteristics of the metal piece through which the discharge takes place. Also, M. Masugi [6] has studied the stability of the ESD current waveforms for various speed discharges using multiresolution analysis.
To the measurement of the electromagnetic field had been paid less attention until the end of 80's. Wilson and Ma [7] were the first, who simultaneously measured the current and the electric field during electrostatic discharges at a distance of 1.5 m, using a broadband, TEM horn antenna. During the last years many researchers have conducted the measurement of the electromagnetic fields associated with the ESD event. David Pommerenke [4] measured the electric and the magnetic field at a distance between 0.1 and 1 m, for both air and contact discharges. He found that the magnitude of the magnetic field strongly depends on the 1/R factor (R being the distance from the point where the ESD occurs), while the magnitude of the electric field is decreasing for a time period after which increases. There have been also studies [8, 9], where the ESD current waveform can be calculated measuring the electromagnetic field. David Pommerenke and Stefan Frei [10] have also designed an impulse monitoring system, which automatically detects electrostatic discharges by their associated magnetic and electric fields.

2 THE EUROPEAN STANDARD EN 61000-4-2

The European Standard 61000-4-2 [11] 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., which may exist in allocations classified in Standards relevant to electric and electronic equipment.
A wide variety of engineering models have been proposed to simulate electrostatic discharge events but in general they fall into two categories [2]. The first one is the Human Body Model (HBM), which simulates the direct contact of a charged human body and a component. The second is the Charged Device Model (CDM), which simulates the contact between a charged component with another component. The major difference between these two models is the rise time and the fall time of the ESD current pulse. The HBM current waveform has typically a rise time less than 10 ns and fall time between 50 and 300 ns. The CDM current waveform has typically a rise time and fall time below 1 ns and 10 ns respectively.
According to the Standard EN 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 calibration of the ESD generators the discharges are contact discharges and not air discharges.

The ESD generator must produce a HBM pulse as it is shown in figure 1.

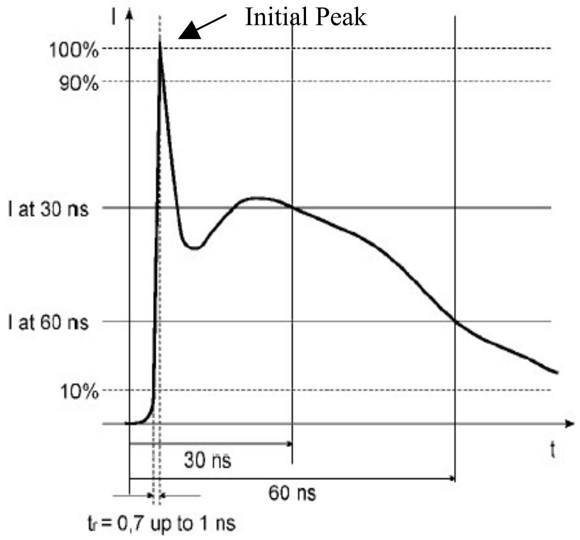

Figure 1: Typical waveform of the output current of the ESD generator [11].

The pulse of figure 1 is divided into two parts: A first peak called as “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.

3 THE DIPOLE SOURCE MODEL

Wilson and Ma [7] developed a model for the ESD discharge and they gave the analytical equations for both the electric and the magnetic field. The ESD discharge was modelled by an electrically short time dependent linear source (dipole-dz), as it is shown in figure 2.

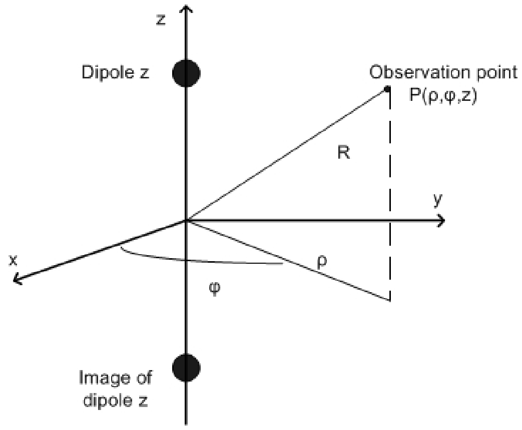

Figure 2: The dipole source model.

The magnetic field strength in the direction of φ can be calculated by the following equation working in cylindrical coordinates (ρ, φ, z) (1):

$$H_{\phi}(R,t) = \frac{1}{4\pi}\left(\int_0^z \frac{\rho}{R^3} i(t)dz' + \int_0^z \frac{\rho}{cR^2}\frac{\partial i(t)}{\partial t}dz' \right) \quad (1)$$

where c is the speed of light, R is the variable representing the distance from the source to the observation point, ρ is the projection of R on the x-y plane, t is the time, dz′ is the length of the electric dipole source, z is the total length of the current path and φ is the angle between ρ and the x-axis. Equation (1) suggests that the magnetic field is depending on two factors: a) the current i(t), which dominates in the near field zone and b) the current derivative $\frac{\partial i(t)}{\partial t}$, which dominates in the far field zone.

Equation (1) is often misunderstood or misapplied. In reality a time retarded integration over the complete current density of the body, not only the current at the discharge point is needed. This leads to large differences. For example, in the near field (a few cm) the magnetic field must follow Amperes law in its simplest form, so the magnetic field must be proportional to the current (not its time derivative). In the far field the magnetic field again should follow 1/R, but the wave shape should be proportional to the time derivative of the current that is integrated (with correct retardation) over the structure.

4 MEASUREMENT SYSTEM

Figure 3 shows the ESD current experimental set-up. The current and the magnetic field (H-field) for various charging voltage levels, were measured simultaneously, by the 4-channel Tektronix oscilloscope model TDS 7254B, whose bandwidth ranged from dc to 2.5 GHz. Four (4) Schaffner’s ESD generators produced air electrostatic discharges. Although there is a reproducibility problem for the air discharges due to the different electric arc of each air discharge the compared waveforms of the H-field have been obtained through repeatable measurements, for the same peak current. Since the peak current is the same the electric arc is also the same and consequently, the H-field waveforms are comparable.

The ESD generators used were the NSG-430 for positive discharges, NSG-430 for negative discharges and NSG-433, NSG-438 for positive discharges. In order the measurement set-up to be unaffected by surrounding systems, the experiment was conducted in an anechoic chamber. The generator’s capacitance was charged with a positive polarity of charging voltage 1 kV and 2 kV. The temperature and relative humidity were measured and found in the ranges 27±1°C and 38±3%, respectively.

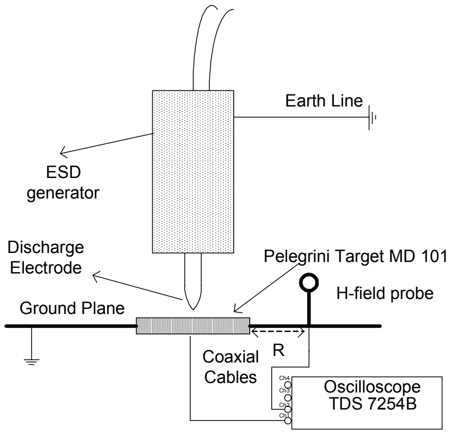

Figure 3: Experimental set-up.

In order the current to be measured a resistive load was used, as the European Standard defines. This resistive load (Pellegrini target MD 101) [12, 13] was designed to measure discharge currents by ESD events on the target area and its bandwidth is ranged from dc to above 1 GHz. Figure 4 shows the insertion loss of the target, where it is obvious that MD 101 has a linear behaviour from dc until almost 5 GHz. The equivalent circuit of the measurement set-up is also shown in figure 5.

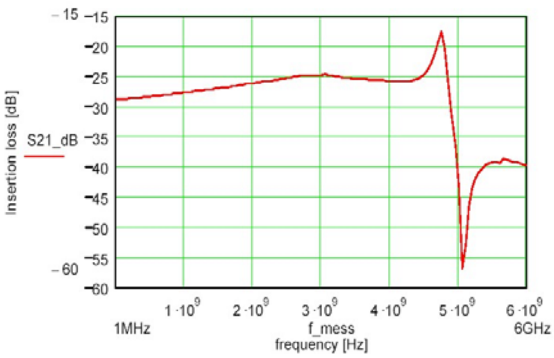

Figure 4: Insertion loss of the Pellegrini target MD 101 [12].

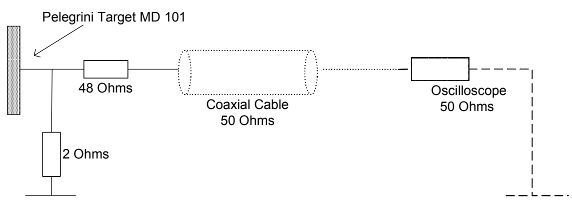

Figure 5: Equivalent circuit of the measurement set-up.

The strength of the magnetic field (H-field) was measured using the HZ-11 set of Rohde & Schwarz, which is consisted of five passive near field probes. The H-field probe, which was used for the measurement of the magnetic field capable of measuring signals up to 2.5 GHz. The probe was a loop probe of 10 mm in diameter and it was placed at various distances R from 10 cm to 55 cm and in one direction from the discharge point, as it can be seen in figure 3.

5 EXPERIMENTAL RESULTS

A typical oscillogram of the 4-channel Tektronix oscilloscope model TDS 7254B can be seen in figure 6. Channel 1 (yellow line) measures the ESD current, while simultaneously channel 2 (blue line) measures the radiating H-field from the ESD. The waveforms depicted have derived using the NSG-438 ESD generator.

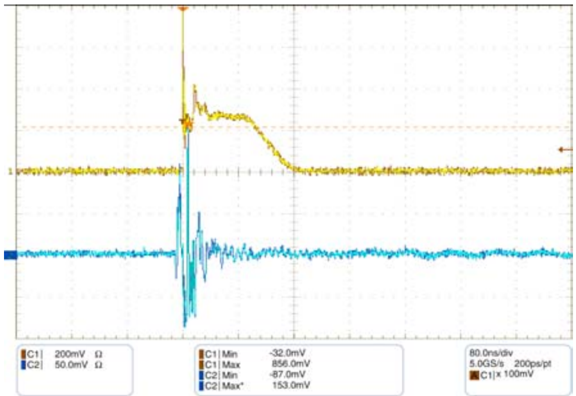

Figure 6: A typical oscillogram for a 2 kV charging voltage of the NSG-438 ESD generator. The yellow line (channel 1) is the measured discharge current and the blue line (channel 2) is the measured magnetic field.

In figure 7 the H-field for various distances R (10 cm, 30 cm, 50 cm) from the discharge point for 1 kV charging voltage (ESD generator NSG 438) is shown. It can be concluded that the magnitude of the H-field strongly depends on the distance and it is proportional to the 1/R factor. Also, the magnetic field follows the change of the current. This is also the reason that the H-field has negative values.

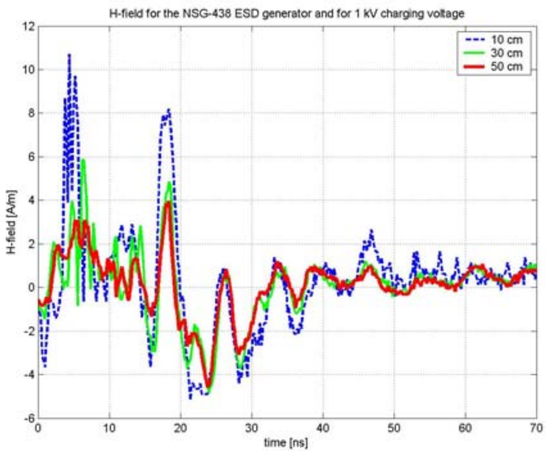

Figure 7: H-field for various distances for 1 kV charging voltage of the NSG-438 ESD generator.

The magnetic field corresponds in the opposite direction to the variations of the current as it can be clearly seen in the oscillogram of figure 6. The peak value of the H-field of figure 7 appears between 0 ns and 5 ns, for the three different distances. The time difference between the 4 ns at which the H-field is maximized and the 1 ns, when the current receives its peak value is due to the time the electromagnetic wave needs to travel to the point, where the H-field probe is placed. Same conclusions arise also for the second peak of the H-field, which takes place at about 19 ns.

In figure 8 the peak value of the H-field for various distances from the discharge point and for a 1 kV charging voltage is shown. All the five depicted points at 10 cm, 20 cm, 30 cm, 45 cm and 50 cm have been chosen because in all of them the maximum discharge current is the same and equals to 0.508 A. Therefore, such a comparison is possible. It is obvious that H_{max} decreases hyperbolically with the increase of the distance. Due to the fact that the discharges are air discharges and not contact discharges the produced electric arcs are different and therefore the discharge currents and their peaks are also different. This stochastic phenomenon explains why in some cases the magnetic field is higher in greater distances. Also, this explains why for the calibration of the ESD generators the discharges are contact discharges and not air discharges as it was mentioned previously.

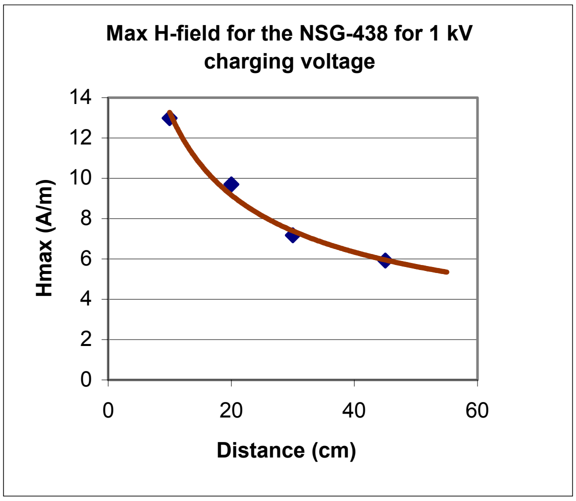

Figure 8: Peak of H-field for various distances from the discharge point using the ESD generator NSG-438 and for the same peak discharge current.

In figure 9 a comparison of the transient field that each of two ESD generators (NSG-430 and NSG-438) produce is shown. The comparison has been made for 2 kV positive charging voltage and for a distance of 35 cm from the discharge point. The transient field that the NSG-438 produces is higher than this one of the NSG-430 also for the same voltage of 2 kV. The different transient field that each ESD generator produces is a significant factor for problems that some times occur.

The different induced voltages on examined EUT (Equipment Under Test) sensitive to slight disturbances (as for example integrated circuits) may have different results. The same device passes the test with one ESD generator and fails with another. An important factor that this happens is the different electromagnetic field that each ESD generator produces. This is a reason why there is a need the next revision of the EN-61000-4-2 to take into consideration this remark, in order the limits of the produced transient fields to be defined and unified.

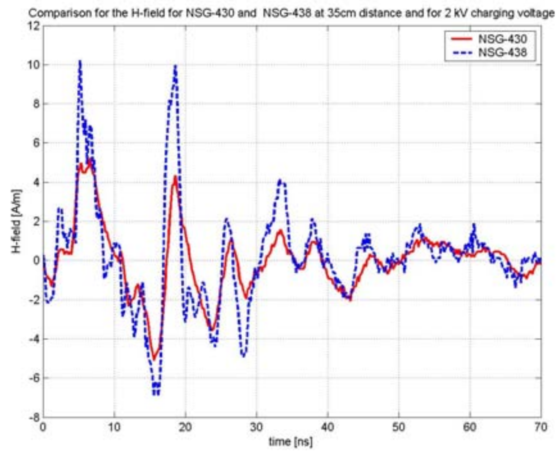

Figure 9: H-field comparison between 2 ESD generators at 35 cm distance and for a 2 kV positive charging voltage.

In figure 10 a comparison of the transient field that two ESD generators of negative discharges (NSG-430 and NSG-433) produces is shown. The comparison has been made for a 2 kV negative charging voltage and for a distance of 35 cm from the discharge point. The transient field that the NSG-430 produces is higher than this of the NSG-433 and for the same voltage of 2 kV. Also due to the negative polarity the peak value of the magnetic field is also negative, since the magnetic field curve follows the changes of the current.

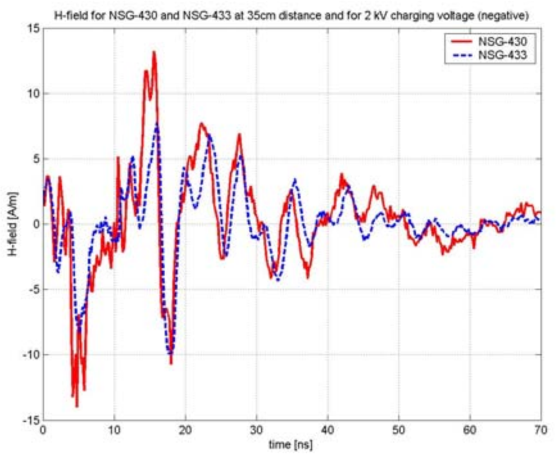

Figure 10: H-field comparison between 2 ESD generators at 35 cm distance and for a 2 kV negative charging voltage.

Comparing figures 9 and 10 it is concluded that the differences between the produced transient magnetic fields are due to the different peak discharge current of each generator.

6 CONCLUSIONS

A theoretical and experimental approach has been carried out in order the transient magnetic field of the electrostatic discharge to be investigated. The transient magnetic field produced by four (4) different ESD generators for both negative and positive discharges was measured. The comparisons showed that each generator produces a different magnetic field. Due to this fact there are different results when EUT are tested. Therefore, there is a need the next revision of the EN-61000-4-2 to take into consideration this remark, in order the limits of the produced transient fields to be defined and unified.

Future work must include measurements of the radiating electric field. Also, there must be measurements for both the magnetic and electric field for contact discharges as well with air discharges, in order useful conclusions to derive for the produced fields by the ESD generators. Furthermore, a computing method for the calculation of the electromagnetic field radiated by electrostatic discharges must be applied and a comparison with the measured data to be made.

7 ACKNOWLEDGEMENTS

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