Prolongation of Double RLC Model for ESD Manifold Events

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Abstract- The starting point of our work was focused around some phenomena encountered while testing the ESD immunity of vehicle electrical equipment, mainly using a laptop, an ESD gun and a scope. One target of our approach is to find explanations for the influence of the position of the ground connection of the ESD tester and of the rod geometry and dimension upon the rise time of the injected current into the abovementioned laptop. The scope was a good 500MHz one, with connectivity facilities, inserted in an experimental set-up recommended by IEC. The second target was to extend a model and to set its lumped elements for multiple discharges. We observed during some ESD events, successive pulses, with a decreasing energy level, being separated by a time period lasting tens of milliseconds. We consider that this multiple discharge event could by modelled by up-grading the body metallic model. Scope-tracing many ESD discharge waveforms, we determined the values of the elements from a double RLC scheme with two ground connections, forming self-oscillating circuits with variable attenuation, for allowing the extension from a single discharge pulse to multiple ones.

Keywords: ESD, gun's rod, multiple discharge, dual RLC body metallic model.

I. Background of the problem

One of the contemporary trends in automobiles (design and exploitation) is the continuous growth of electronics as importance and density. But a functioning car is a very adequate place for triboelectricity generation, with so many different materials rubbing together and then rapidly separating. In this framework, ESD received an importance alike other EMC investigations, in the assessment of motor vehicle performance. The increasing circuit density, power efficiency and working frequency of modern electronics are explanations for the high susceptibility to damaging fields and transients. Within this sphere of interest, triboelectricity and connected discharge are to be blamed for many failures in electronics and even information technology.

The accurate and repeatable simulation of ESD using standardized and internationally accepted procedures will partially find out the potential deficiencies in a product. Such Achilles' heel points could be, afterwards, eradicated to improve the global quality of the product through affordable solutions in design, production, packaging, handling and utilisation. It is a common point that the cheapest way for solving a problem is to consider it just from the design phase. But for this, the test methodology and set-up must endeavour to reproduce the reality in a repeatable manner.

II. The starting point

While using a laptop inside the car, in order to proceed the results of our ESD tests, we encountered quite unpredictable upsets, typically manifested by "lock up" of the CPU, fortunately simple solved by RESET-ing the notebook. These upsets occur due to voltage induction and might be explained by the passage of discharge current through the ESD-tester ground connection [1]. This path, conducting a variable current, behaves like a transmitting antenna. We here assume that the dominant transmitting antenna is that portion of the discharge route inside the laptop (interior ground configuration), not the gun rod itself. For modelling the test set-up, human body resistance is approximated by 330 Ω and human body capacitance is approximated by 150 pF, being charged to a voltage between 4 kV and 15kV. Because the gun rod is in contact with the metallic entry point, there is no arc and the points to be made in our experiments mainly apply to contact injection. As a rule, peak currents for arc injection are higher than those for direct contact [2].

III. Rod length influence on discharge waveform

The real global dimension of the experimental set-up is about 120 cm, meaning that the wave needs 4 ns to cross it, a longer period than the usual discharge current rise time. So, the transmission line approach is more adequate than a lumped circuit one. Using a commercially available transmission line analysis program, assuming an average characteristic impedance $Z_0=(L/C)^{1/2}=500\Omega$, we studied the effect of rod dimension and shape on discharge current waveform. Were considered usually encountered rod length, between 2 and 20 cm. We assumed the transmission line model, here comprised of the gun rod and the vertical part of the gun ground strap, fig.1.

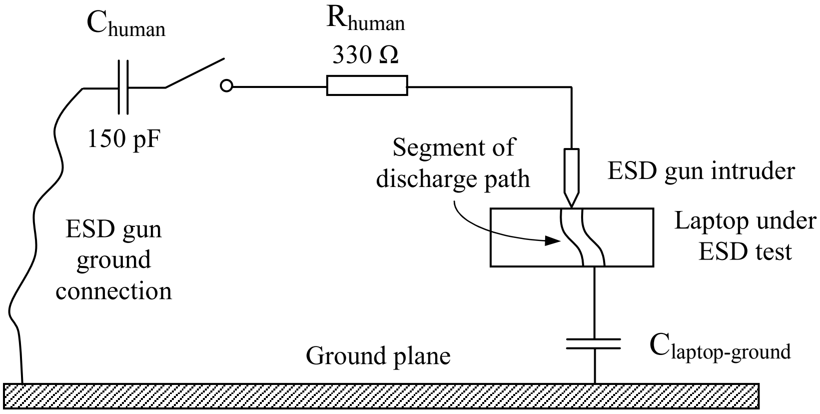

Fig. 1. Laptop under ESD test, transmission-line model assumed

We have noticed that a longer rod enhances the sequential width of the horizontal part of the stair-step discharge current, while the tallness of the stairs remains unchanged (particular situation when the impedances of the horizontal and vertical transmission line fragment are equal, involving a single set of reflections), figure 2.

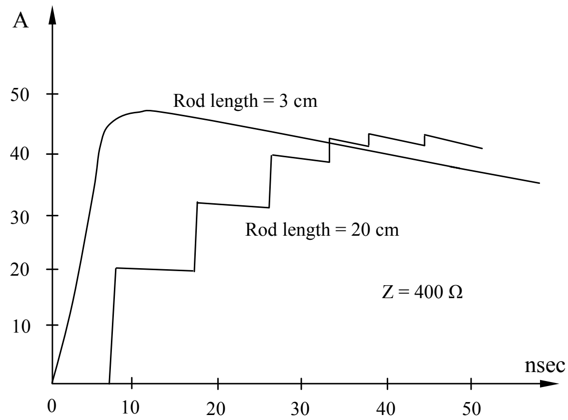

Fig.2. Influence of rod extent on the waveform of the discharge current

We here could note the fast-rise part of i(t) for rod lengths between 3 centimetres and 20 centimetres, the domain that normally includes the rod lengths of the usually encountered ESD guns.

In practice, the stairstep rises in currents are a bit curved by the losses in rod and ground strap and also parasitic inductances and associated with the capacitance and the resistance of the human body and of the switch. Nevertheless, even accepting curved currents, it is obviously that the rise time of current injected into equipment depends on the length of the gun rod. This is important, as the amplitude of voltage induced in circuit loops by electromagnetic waves originating from the ground structure is proportional to di(t)/dt.

The current is also affected by the characteristic impedance of the line, Z, depending on the spacing between the vertical part of the gun ground strap and the rod, the diameter of the gun rod and the construction of the ground strap.

IV. Double RLC model and multiple ESD discharge

Using a good 500MHz scope with connectivity facilities and the experiment set-up recommended by IEC [3], were observed during the discharge, successive pulses, with a decreasing energy level, being separated by a time period lasting tens of milliseconds. We consider that this multiple discharge event could by modelled by assuming the body metallic model, a person with a screwdriver to remove a screw from the vehicle front panel, while rubbing inside the car. Scope-tracing many ESD discharge waveforms, we determined the values of the elements from a double RLC scheme with two ground connections, in order to allow an extension from a single discharge pulse to multiple ones. The proposed (and tested) solution is a self-oscillating resonant circuit, with considerable attenuation, fig. 3.

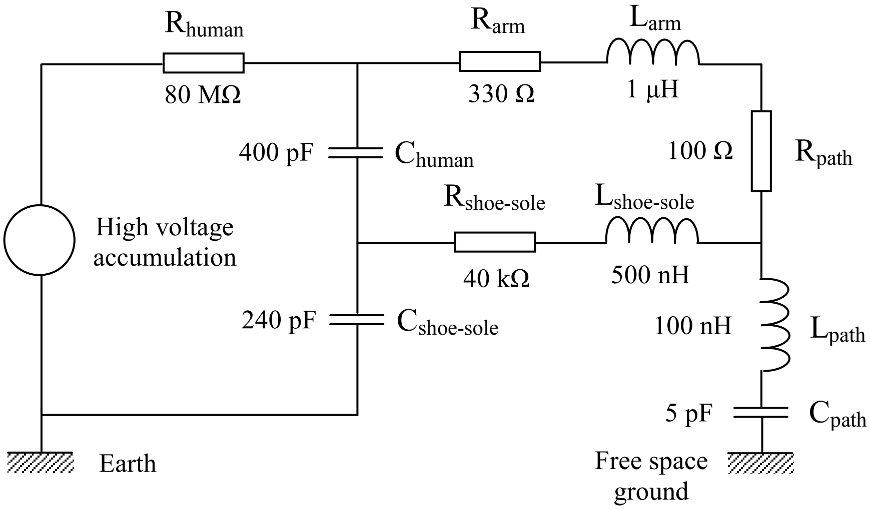

Fig. 3. Proposed extension of the Double RLC Model for ESD Manifold Events

A punctual and comparative evaluation of simulated and real traces and the experienced values for the lump elements is useful and advisable.

The earlier assumed Body Metallic Model presupposes a fairly large value for the impedance of the corpse. By reason of this high impedance, a discharge might occur across the low capacitance associated with the air, between the finger and the object, while the shoe-soles may still maintain a charge. This remaining charge on the feet will recharge the small separating space to object capacitance, until the breakdown voltage is again reached, allowing a consequent discharge. This repetitive charging and discharging is accompanied by ESD multiple discharges. In consideration of the realistic body impedance, the corresponding time constant will be on the order of tens of microseconds. This subsequently, explains multiple pulses occurring in short succession.

Taking into consideration the abovementioned development, for multiple discharges separated by even tens of milliseconds, it would be necessary an unacceptable large human-model impedance. Our experiments led to the conclusion that the dielectric absorption of the shoe has relevance, accepting it as an RC circuit with a sizable value of resistance. The consequence is a considerable time constant sustaining the time period between multiple discharges.

In the same time, we appreciate that a complementary mechanism should be considered in the explanation of ESD multiple discharges.

Considering the motion of the finger or the screw-driver toward the DUT, at a specific distance between the intruder and abovementioned DUT, the accumulated energy is sufficient for a spark to be settled. The arc will extinguish when the energy required maintaining the ionisation path is lacking. While finger moves closer to the object, the energy required to start an arc is reduced and a quasi-new spark is again established. The discharges continue until the stored charge is totally finished. This approach seems to be adequate for too large separation periods between the discharges.

ESD events capturing the effect of multiple discharges were stored and depicted in many figures. Specifically, a current waveform is rending for a 10 kV air discharge from a person holding a metal object. This trace is quit similar to that associated for a classical human ESD event, excepting several pulses displayed rather than only one. The consecutive pulses that comprise the total air discharge are superimposed, but a finite time period actually separates each pulsation.

V. Miss-matching at high voltages due to corona effect

In our tests, the ESD multiple discharges were not encountered at relatively high voltage, greater than 10KV. At such high voltage levels, the air in the close neighbourhood of the ESD event is ionised, creating a corona predischarge. While the discharge takes place, the fall down of the ex-static field is the cause of a new dynamic one. Finally, as the charge runs, current is injected into the equipment and, as consequence, an electromagnetic field propagates inside our laptop.

The influence of corona discharge, affecting the shape and the duration of the ESD waveform is underlined in figure 4.

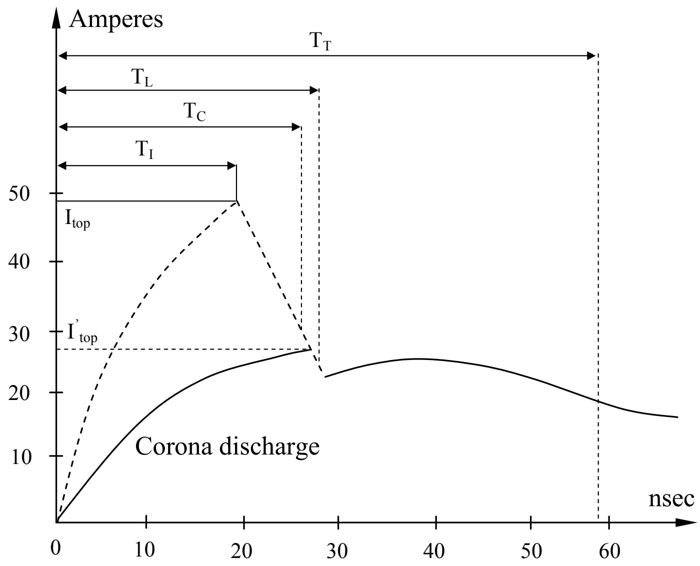

Fig. 4. The common, non-specific ESD current waveform versus corona effects

The fast rise time typically associated with ESD pulses is dramatically reduced at high discharge voltage levels due to the corona phenomenon. The significance of this effect must be carefully considered, as it plays a vital role with regard to multiple ESD discharges.

Figure 4 generally describes ESD current waveform, with or without predischarge. T_I indicates the increase time of the initial ESD pulse. The length of this initial pulse is represented as T_L. The interval of the overall ESD event is nominated T_T. I_{top} signifies the top current of the initial ESD pulse. At higher voltages, typically greater than 3 KV, ESD pulse can range from hundreds of picoseconds to tens of nanoseconds. The pulse width of the initial ESD pulse can be from less than one nanosecond to ten nanoseconds. The top current can vary from less than one to more than one hundred Amperes. Maximum voltages associated with ESD events can range from a few 2-300 to over 20.000 volts.

VI. Conclusions

We concluded that the waveform of current injected into equipment is strongly influenced by gun rod length and by other factors affecting the characteristic impedance: the diameter of the gun intruder, the manufacture and the arrangement of the ground connection.

Another conclusion is that the discharge waveform can be modified by means of gun/ground strap construction and positioning. That tailoring could be done in the light of experimentally measured human body discharge currents. Distribution of resistance nearly approximates the condition of the human body.

We extended the double LRC scheme, by modifying the initial set-up and by calculating the new values, from the single ESD pulse to the happening of several decreasing ones. The identified multiple discharges are characterised by fast rise time and high peak current pulses.

The obtained results are applicable for modelling, prediction, repeatability and timesaving experiments.

References

[1] Kenneth Keenan, Leonard Rosi, *Some Fundamental Aspects of ESD Testing*, IEEE International Symposium on Electromagnetic Compatibility, pp.236-241, 1991.

[2] Russell C. Pepe, *ESD Multiple Discharge*, IEEE International Symposium on Electromagnetic Compatibility, pp.253-258, 1999.

[3] T. Williams, *EMC For Systems and Installations*, *Newness*, Oxford, UK, pp. 258-260, 2000.