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Design and Verification of Equivalent Circuit for Cable Electrostatic Discharge

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Abstract

In the process of production, transportation and assembly, cable assemblies can get a lot of electrostatic charge by friction, dragging, pulling and induction. These residual charges can be discharged when Electrostatic sensitive device connected with it and can cause the complete failure or potential failure of the electrostatic sensitive product. In this paper, the theoretical model of cable assemblies is established by analyzing the characteristics of cable assemblies, and the equivalent RF circuit is designed. The static discharge characteristics of the cable are analyzed and verified by simulation.

Keywords

Cable Discharge, Theoretical Model, Equivalent RF Circuit, ADS Simulation

1. Introduction

Cable electrostatic discharge has a very serious hazard. There is a big difference between the discharge process and the more common HBM high impedance and low capacitance structure. The cable discharge will cause higher current than other ESD. The cable is equivalent to the capacitive element, which can store the charge, and the capacitance value will increase with the length of the cable. In the event of a friction effect (such as the production process of the pulling cable) or electromagnetic induction effect (such as the interference of the adjacent traction cable), cable will be filled with a thousand volts of high voltage, the accumulated charge can reach the other ESD model of the charge on a hundred times. The comparatively new CAT5 and CAT6 cable with a very low dielectric leakage, the charge can be stored for several hours in a low relatively humidity environment. When the charging cable is inserted into the port, the accumulated charge retention can cause substantial damage. And the position of cable discharge usually occurs in the communication interface with poor static electricity protection, and there is no current limiting resistance. Transient current will choose the lowest impedance path to discharge in a very short time. It can cause huge discharge current, the reliability and safety of components to produce a great threat.

The electrostatic discharge waveforms of the cable have a fast rising edge, and are accompanied by the phenomenon of polar reversal. The discharge waveform parameters change with the characteristics of the cable (such as length, shape) and environment (temperature, relatively humidity). The existing test shows that the dis-

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charge waveform of the cable is not related to the cable type [1], and is related to the cable length and cable shape. The CDE waveform of 7.6 m cable is only sustained by 600 ns, and the CDE waveform of 100 m cable can last up to 15 s. Due to the capacity of the cable, longer cable means the lower oscillation frequency and the shorter the cable, the higher the oscillation frequency is.

At present, many developed countries investment a high degree of attention in cable electrostatic discharge and they recognized the great harm of the cable discharge. America has been carried out cable discharge event (CDE) research. The analysis results show that the cable can be charged by the friction, electricity and contact charge. Electrostatic charge release can cause damage or failure of components. WG14 ESDA working group was set up to study the mechanism of electrostatic discharge damage, but not yet published a special technical report. However, the discharge of the cable has not caused enough attention in China, the crisis awareness of the cable discharge is not strong, the related research progress is slow and there are many problems:

1) The mechanism of electrostatic is not clear and the discharge model of cable is not uniform;
2) There is no specific standard in the existing cable electrostatic protection technology and operation specification;
3) There is no basis for electrostatic protection design of cable assemblies and technical means of test verification.

2. Theoretical Model

A cable is similar to a pole of capacitor, and the other pole is ground. The charge quantity is proportional to the length of the cable, and is inversely proportional to the distance between the two electrodes. For a cylindrical inner core cable, the capacitance between the ground plane can be obtained by theoretical calculation:

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{d+\sqrt{d^2-r_{wire}^2}}{r_{wire}}\right)}\cdot L_{wire} \tag{1}$$

According to W. Stadler's experiment in "Cable Discharges into Communication Interfaces" [2], it is known that the cable discharge is independent of cable type. In this paper, the cable model is chosen with a distance of 0.5 meters between cable and ground and a cable radius of 0.01 meters. The capacitance value of the cable unit length is 12pF, and the product of capacitance and inductance is constant:

$$LC = \mu_r\varepsilon_r\mu_0\varepsilon_0 \tag{2}$$

The relative magnetic permeability is 1 H/m, and the permeability is $4\pi\times10^{-7}\,\mathrm{H/m}$. Because the cable is wrapped by an insulating sheath, the relative permittivity is slightly higher than that of the dielectric constant of the air, so take the experience value 1.08 F/m. the dielectric constant of the vacuum is $8.85\times10^{-12}\,\mathrm{F/m}$. The unit length inductance of cable can be calculated as 1 μH. Characteristic impedance can be calculated by the known capacitance and inductance of the cable. Cable discharge time is short, and low frequency circuit analysis cannot meet the requirements of discharge cable, so we need to analyze the discharge process in the RF field.

In the RF circuit design, the current and voltage are no longer the space invariants. Thus Kirchhoff's voltage and current law cannot be applied to the whole macro length, when the cable is cut into infinitesimal, these elements to include all relevant electrical characteristics. Such as the inductance and capacitance effect of transmission line. This representation of segmentation element can introduce the description of distributed parameter. The analysis of this description in the micro dimension follows Kirchhoff's law, and it can provide a clear and intuitive physical image analysis, as shown in **Figure 1** [3].

Kirchhoff's voltage law:

$$-\frac{dV(z)}{dz} = \left(R + j\omega L\right)I(z) \tag{3}$$

Kirchhoff current law:

$$-\frac{dI(z)}{dz} = \left(G + j\omega C\right)V(z) \tag{4}$$

Characteristic impedance:

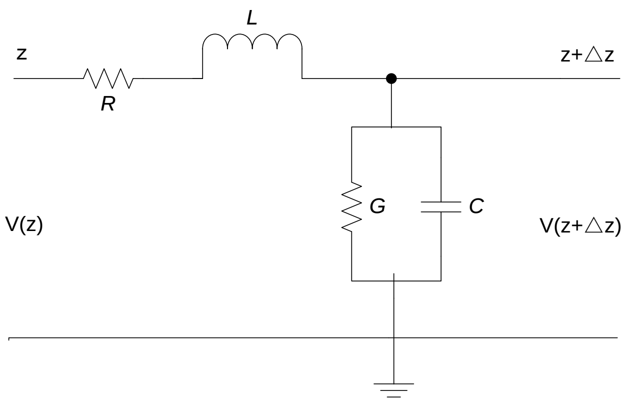


Figure 1. Element analysis of a cable.

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{5}$$

The loss caused by the electric resistance and conductance in the cable model will not cause considerable errors, and can be neglected:

$$Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{1\times10^{-9}}{12\times10^{-12}}} = 288.675\Omega \tag{6}$$

The impedance of the unit length is 288.675 Ω.

3. The Design of Equivalent Circuit

After calculating the characteristic impedance of the cable, the cable discharge circuit can be designed. Cable not only has the characteristics of capacitance, but also the inductance characteristics, the discharge waveform generally has a fast rising edge, and with a polar reversal of the oscillation phenomenon. In order to analyze the transient characteristics of cable discharge, this paper chooses the powerful RF circuit simulation software ADS to complete the circuit simulation analysis. Cable discharge circuit should be mainly composed of two parts, that is, charging cable and discharge object. In the ADS, discharge of the cable cannot be simulated directly, so microstrip line which has similar structure with cable is chosen [4].

As shown in **Figure 2**, the microstrip line with a width of 1.42 mm has the same characteristics as the cable with a radius of 10 mm. So the charging cable is chosen to replace by a microstrip line with a width of 1.42 mm.

As shown in **Figure 3**, on the right side of the microstrip line, the capacitor and the inductor are used to simulate the capacitor and the inductance of the wire that connect the microstrip line and discharge object. W. Stadler in "Characterization and Simulation of Real-World Cable Discharge Events" chose the ground plate as the discharge object [5]. However, the input impedance of the oscilloscope cannot be matched by the discharge object, and this will cause reflection, so as to interfere with the discharge waveform. And choosing the ground plate as the discharge object has no practical engineering significance. In this paper, the discharge object is designed as the impact element which is protected by the protective capacitance. We select a microstrip line with a length of 40 mm and a width of 8.21 mm to simulate the element pin which has a characteristic impedance of 25 Ω. And we add a protective capacitance of 20 nf before the microstrip line, and add a matching resistor after the microstrip line to match the impedance of the 50Ωwith the input impedance of the oscilloscope so as to prevent reflection.

4. Simulation Verification

Charge the different length cable with different voltage and observe the voltage waveform and current waveform of the discharge, and verify the correctness of the equivalent circuit, as shown in **Table 1**.

As shown in **Table 2**, when the charging voltage reaches 1.5 KV, in spite of capacitor protection, the pin

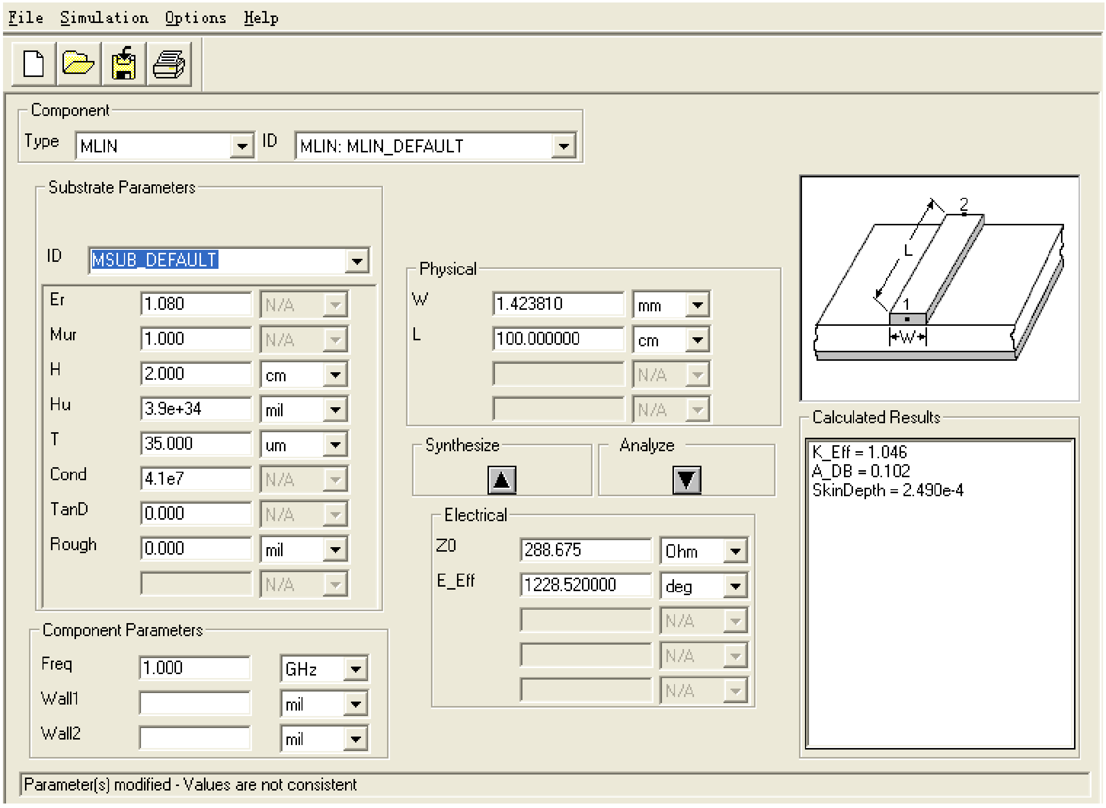


Figure 2. Simulation parameters of microstrip line.

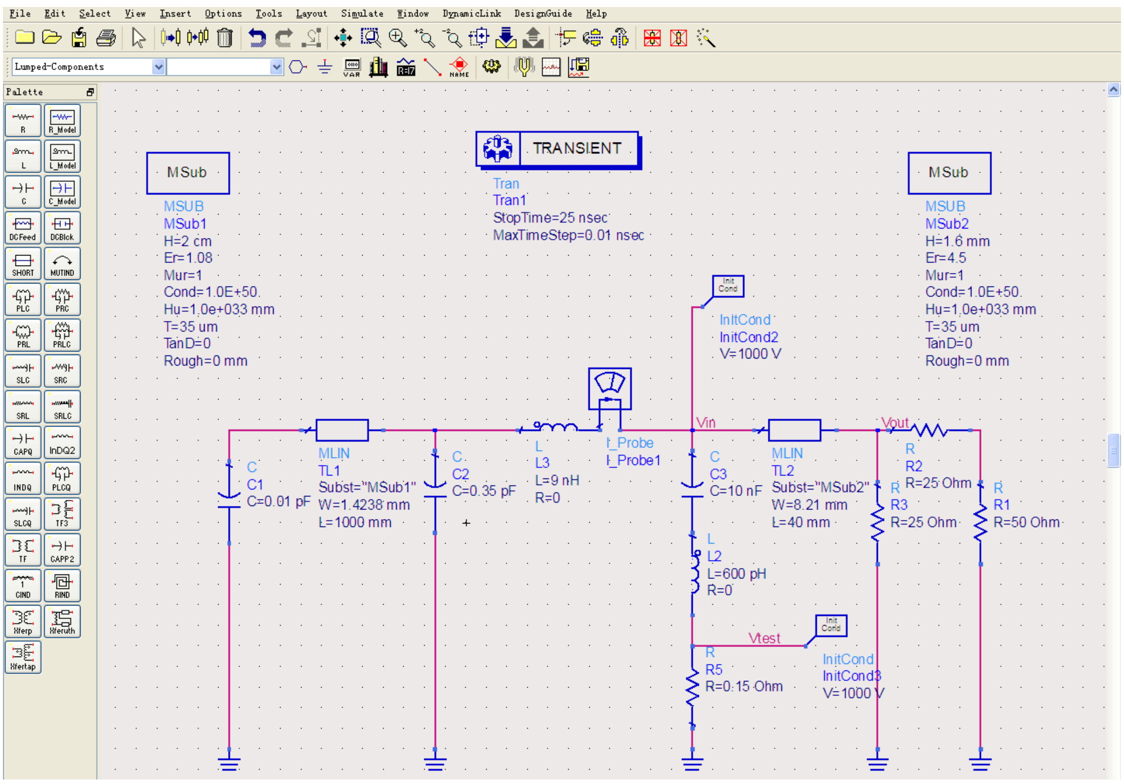


Figure 3. Equivalent circuit of cable discharge.

voltage spike of the device will exceed the pressure limit 40 V, which conforms to the calculation in Bastian Arndt's paper of "Comparing Cable Discharge Events to IEC 61000-4-2 or ISO 10605 Discharges". 1.5 kV should be recommended as the risk voltage of cable charging voltage [6].

The pulse width of the cable discharge is calculated as follows [7]:

$$t_{pulse} = \frac{2 \cdot l_{wire} \cdot \sqrt{\varepsilon_R}}{c} \tag{7}$$

So the cable length of 1m has the pulse width appointment of 6.7 ns and the discharge pulse width of a charged cable is linear with the length of the cable. The voltage waveform obtained from the simulation circuit accord with the theoretical calculation of the pulse width.

From the **Table 3** we can see that the risetime of cable discharge current is only about 0.1ns, and it has nothing to do with the cable length and load voltage.

5. Conclusion

The cable itself is a linear device, and has a linear characteristic. From the above table, we can see that the relationship between the discharge current and the charging voltage is linear and the parameters of simulation such as pulse width, rise time, current amplitude and voltage spike, can meet the result in theoretical arithmetic. In the waveform of the discharge current, after a fast rising edge, current waveform is accompanied by the phenomenon of polar reversal, which conforms to the transient characteristics of the cable discharge. In conclusion, The design of equivalent circuit in this paper is satisfactory and convincing, which can provide the theoretical and

Table 1. Voltage waveform.

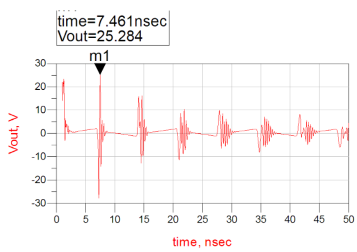
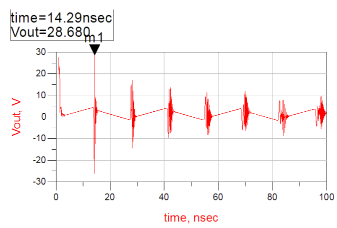
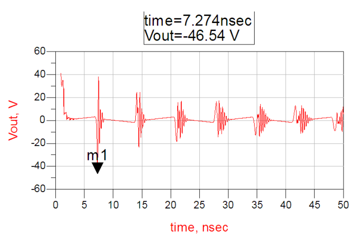
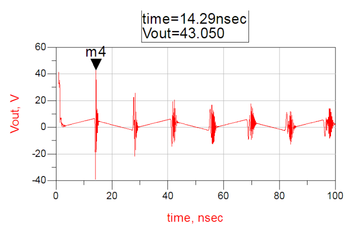
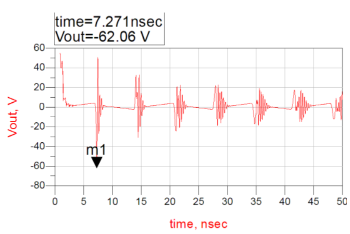
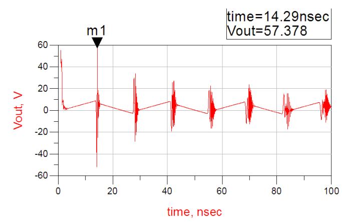
Voltage	Waveform	
	1 m	2 m
1000 v		
1500 v		
2000 v		

Table 2. Current waveform.

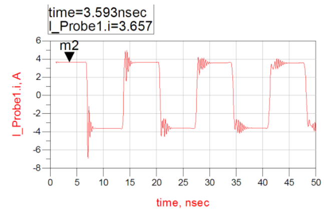
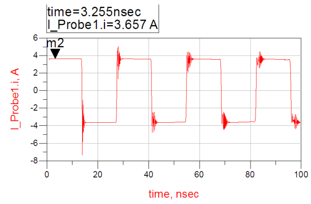
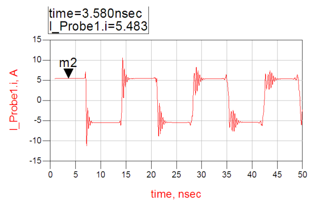
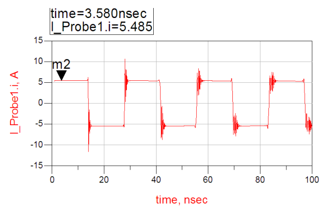
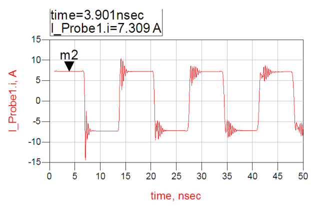
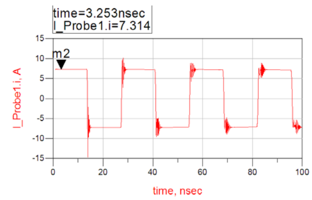
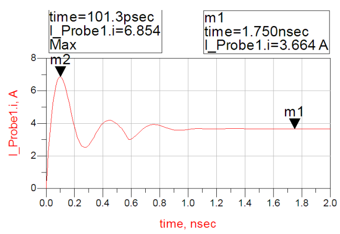
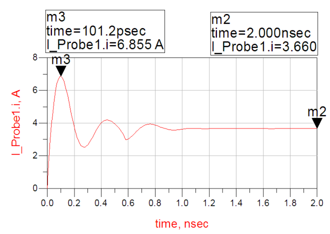
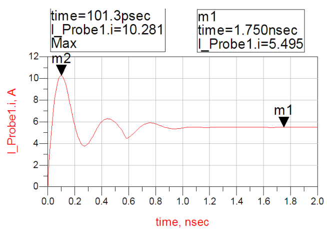
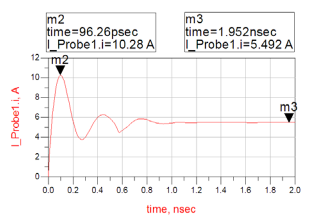
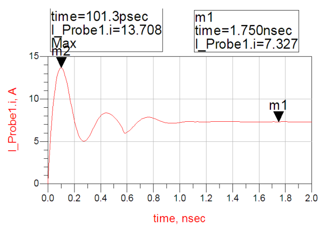
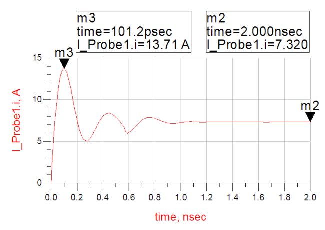
Voltage	Waveform	
	1 m	2 m
1000 v		
1500 v		
2000 v		

Table 3. Risetime.

Voltage	Waveform	
	1 m	2 m
1000 v		
1500 v		
2000 v		

technical support for the further research on the cable discharge.

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