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The Influence of Inductance on the ESD Current by Numerical Computation

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Summery

The ESD current waveforms is modeled by numerical computation. It shows that the inductance influences not only the rise time but also the peak current. The small the inductance, the short the rise time and the large the peak current. The peak current dependent upon not only the initial potential in the capacitance and the resistance but also the inductance. The influence of the inductance to the effect of ESD damage can not be neglected. It is the main factor which influence whether the waveform is oscillate or not, the peak current and the rise time. It also is one of the main factors which influence the damage of the ESD.

1. Introduction

In order to study the electrostatic discharge (ESD)problems, many ESD models have been established such as HBM, CDM, FUM, MM [1]and so on. The research of the capacitance and the resistance is one of the major points because it is easy to measure the capacitance and the resistance by conventional instrument and they are the important parameters in the evaluation of the ESD damage. The research of the inductance in the ESD such as the inductance in the human body ESD circuit is often ignored. With the thorough study of the ESD problem , the effect of the inductance to the rise time of the ESD is very obvious when the rise time is several ps (10^{-12} s). This paper is to investigate the effects of the inductance on the ESD by numerical computation.

2. RLC model

Considering the capacitance, inductance and the resistance serial circuit, the differential equation of the circuit is as follow when the initial voltage of the capacitor is V_0 .

$$u_c(t)+L\frac{di(t)}{dt}+Ri(t)=0 \tag{1}$$

$$i(t)=C\frac{du_c(t)}{dt} \tag{2}$$

$$i(0)=0, \qquad u_c(0)=V_0$$

where R stands for the total resistance in the circuit, L denotes the inductance in the circuit and C means the capacitance.

If the resistance R is constant in the discharge process, from equation (1) and (2) we can get:

$$LC\frac{d^2i(t)}{dt^2}+RC\frac{di(t)}{dt}+i(t)=0 \tag{3}$$

Let

$$\alpha=\frac{R}{2L}$$

$$\beta=\sqrt{(\frac{R}{2L})^2-\frac{1}{LC}}$$

Three different cases can be considered about the solution:

(1) The solution of the waveform is damping oscillation when $R<2\sqrt{L/C}$. The current waveform of the furniture ESD model[2], machine ESD model is in this case.

$$i(t) = \frac{U}{\omega L} e^{-\alpha t} \sin \omega t$$

ω represent the angle frequency

$$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

If $R \to 0$, the waveform becomes oscillation.

(2)In the case of $R > 2\sqrt{L/C}$, the solution of equation (3) is over damping decay. The waveform of the human body discharge is in the case.

$$i(t) = I_0(e^{-t/\tau_d} - e^{-t/\tau_r})$$

where

$$\tau_d = \frac{1}{\alpha - \beta} = RC\frac{1+\sqrt{1-4L/R^2C}}{2} \quad (4)$$

$$\tau_r = \frac{1}{\alpha + \beta} = RC\frac{1-\sqrt{1-4L/R^2C}}{2} \quad (5)$$

$$I_0 = \frac{V_0}{L} \cdot \frac{1}{2\beta} = \frac{V_0}{R} \cdot \frac{1}{\sqrt{1-4L/R^2C}} \quad (6)$$

The solution is in double exponents form. The rise time is depend upon τ_r and the decay time is depend on τ_d

(3) In the case of $R = 2\sqrt{L/C}$, the solution is in the critical damping.

$$i(t) = \frac{U}{L} t e^{-\alpha t} \quad (8)$$

The computational waveforms corresponding the above cases are shown in Fig.1

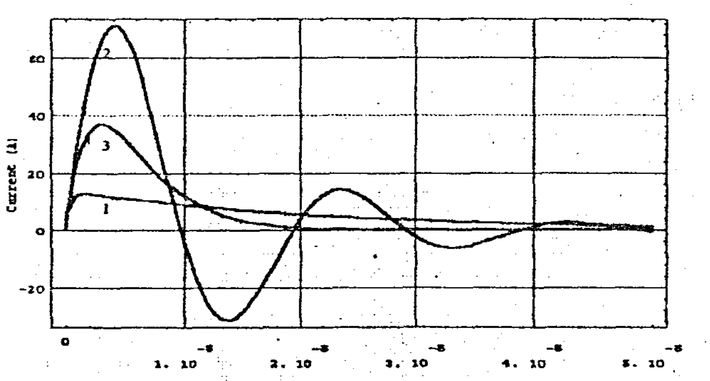

Fig.1 Computational current waveforms for different resistance for C=150pF, L=60nH, V_0=2000V

curve 1: R=150 Ω, $R > 2\sqrt{L/C}$, over damping decay

curve 2: R=10 Ω, $R < 2\sqrt{L/C}$, damping oscillation

curve 3: R=40 Ω, $R = 2\sqrt{L/C}$, critical damping decay

3. The effects of the inductance to the current waveform

The rise time τ_r and decay time τ_d are shown in table 1 when R=330 Ω, C=150PF according to (5) and (6) for different inductance.

Table 1 τ_r, τ_d for different R, C and L

L(H)	R( )	C(pF)	RC(s)	L/R(s)	(s)	(s)

1E-8	330	150	4.95E-8	3.0303E-11	3.03216E-11	4.94679E-8
1E-7	330	150	4.95E-8	3.0303E-10	3.04908E-10	4.91951E-8
1E-6	330	150	4.95E-8	3.0303E-9	3.24273E-9	4.62573E-8
4E-6	330	150	4.95E-8	1.21212E-8	2.82944E-8	2.12056E-8

Comparing the value between L/R and τ_r in table , it can be seen that the value of inductance divided by resistance is the main factor which influence the rise time. The smaller the inductance and the larger the resistance, the shorter the rise time. Comparing the value between RC and τ_d, the product of the resistance and the capacitance is the main factor which influences the decay time. The formula of (5) and (6) can be expanded as series:

$$\tau_r = \frac{L}{R} + \frac{L^2}{R^3 C} + 2\frac{L^3}{R^5 C^2} + 5\frac{L^4}{R^7 C^3} + \cdots \tag{9}$$

$$\tau_d = RC - \frac{L}{R} - \frac{L^2}{R^3 C} - 2\frac{L^3}{R^5 C^2} - 5\frac{L^4}{R^7 C^3} - \cdots \tag{10}$$

When the inductance L is small and the resistance and the capacitance is large, the items which contain the high power order of L/R can be neglected. In this case, τ_r is equals to L/R and τ_d is equals to RC .

The computational current waveform corresponding the parameters in table 1 are shown in Fig. 2, Fig. 3, Fig. 4 and Fig.5.

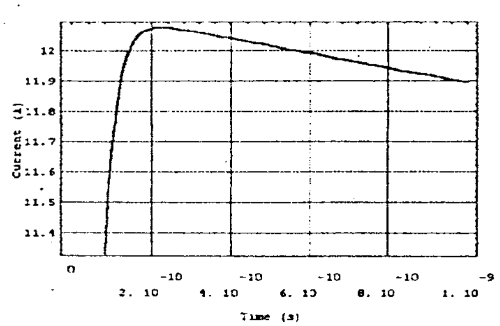

Fig. 2 Computational ESD current waveform
C=150PF, R = 330Ω, L=10nH, V=4 kV

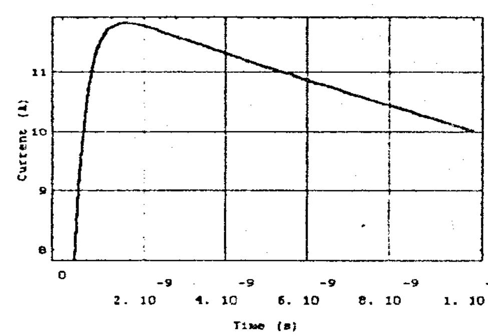

Fig.3 Computational ESD current waveform
C=150PF, R = 330Ω, L=100nH, V=4kV

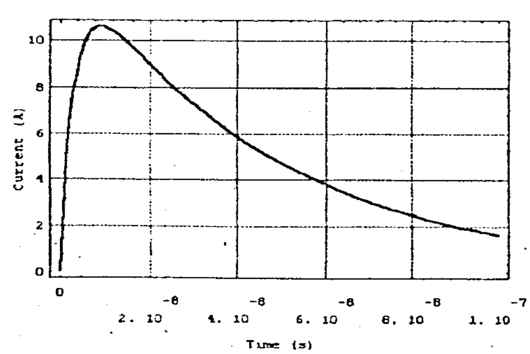

Fig. 4 Computational ESD current waveform
C=150PF, R = 330Ω, L=1 μH, V=4kV

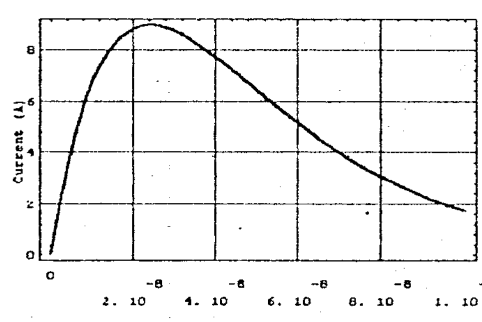

Fig.5 Computational ESD current waveform
C=150PF, R = 330Ω, L=4 μH, V=4kV

4. CONCLUSIONS

It can be seen from the numerical computational waveforms that: (1) the inductance influences not only the rise time but also the peak current. The small the inductance, the short the rise time and the large the peak current. (2) The peak current dependent upon not only the initial potential in the capacitance and the resistance but also the inductance. The influence of the inductance to the effect of ESD damage can not be neglected. It is the main factor which influences whether the waveform is oscillate or not, the peak current and the rise time. It also is one of the main factors which influence the damage of the ESD.

5. References

[1] Owen J. McAteer. Electrostatic discharge control. McGraw-Hill Pub, 1990

[2] Calcavecchio R. J., Pratt D. J. A studard test to determine the susceptibility of a to electrostatic discharge. Proceedings of the 1986 IEEE EMC, 475-481.