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Why the Human Body Capacitance is so Large

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Abstract - The test methods for human body electrostatic capacitance are analyzed. The results shown that in some circumstances the human body resistance and the human leakage resistance from the body to ground can influence the readings of conventional capacitance meter greatly when using the meter to measure human body capacitance. A new test method for the measurement of human body electrostatic capacitance is recommended.

Introduction

The human body model (HBM) is one of the most important model in the ESD damage models. The human body capacitance and the resistance are the main elements in the model. In 1962, National Bureau of Mines Bulletin[1] reported 22 tests showing an average human body capacitance of 204 pF with a range of 95 to 398 pF. W. Kirk et. al [2] reported the human body capacitance from 132 to 190 pF. The Navel Sea Systems Command arrived at a "standard model" of 100pF capacitance in series with 1.5kΩ[3] resistance.

It is simple to measure the capacitance between two conductors, but it not easy to accurately measure the capacitance of human body to the ground. The capacitance may be different from one people to another but the readings of the capacitance meter may be very large for the same human body who wear antistatic shoes. Some times the readings may even large from 2000pF to 6000pF. Why the human body capacitance is so large? This paper is to analyzer the influence of the human resistance and the leakage resistance from the body to the ground on the readings of the capacitance meter

I. The elements which influence the readings

If the human resistance between the skin of human body and the probe of the capacitance meter is R_1 and the leakage resistance from the body to the ground is R_2, the human body can be modeled in Fig. 1.

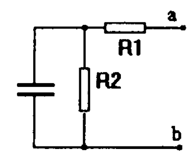

Fig. 1 The human body model

Where C is the real capacitance of the human body. The impedance between "a" and "b" is

$$Z = R_1 + \frac{\frac{1}{j\omega C}R}{R_2 + \frac{1}{j\omega C}} = \frac{R_1 + R_2 + \omega^2 C^2 R_1^2 R_2^2 - j\omega C R_2^2}{1+\omega^2 C^2 R_2^2} \qquad (1)$$

The amplitude of the impedance is

$$|Z| = \frac{1}{1+\omega^2 C^2 R_2^2}\sqrt{(R_1 + R_2 + R_1\omega^2 C^2 R_2^2)^2 + \omega^2 C^2 R_2^4}$$

$$= \sqrt{\frac{R_1^2 + 2R_1R_2 + R_2^2 + R_1^2\omega^2 C^2 R_2^2}{1+\omega^2 C^2 R_2^2}} \qquad (2)$$

In this case, the capacitance is not inversely proportional to the amplitude of the impedance. We consider three different cases:

I.a. The Effect of the Human Body Resistance R_1 to the Readings of Capacitance Meter

Let $R_2 \rightarrow \infty$, in equation (2) and the amplitude of the impedance is

$$|Z_1| = \frac{1}{\omega C}\sqrt{1+\omega^2 C^2 R_1^2} \quad (3)$$

The ration of the readings of the meter in this case to that readings when the human body resistance is zero (R_1=0) is proportional to the impedance for the frequently used AC type capacitance meter.

$$k_1 = \frac{X_c}{|Z_1|} = \frac{1}{\sqrt{1+\omega^2 C^2 R_1^2}} = \frac{1}{\sqrt{1+R_{N1}^2}} \quad (4)$$

Where the R_{N1} is the human body resistance R_1 normalized to the impedance of capacitance C. A plot of the readings k_1, normalized to the readings when the human resistance is zero, versus the human body resistance, normalized to the impedance of the capacitance, is shown in Fig. 2. The reduction of the readings due to the human body resistance is evident when the normalized human resistance is greater than 0.3. This is the case when the human skin is dry and the body resistance is greater or the measurement frequency of the capacitance meter is higher.

I.b. The Effect of the Human Leakage Resistance R_2 to the Readings of Capacitance Meter

Let $R_1 \rightarrow 0$ in equation (2) and the amplitude of the impedance between "a" and "b" is

$$|Z_2| = \frac{R_2}{\sqrt{1+\omega^2 C^2 R_2^2}} \quad (5)$$

The ration of the readings of the meter in this case to that readings of the human leakage resistance is infinite is

$$k_2 = \frac{X_c}{|Z_2|} = \frac{\sqrt{1+\omega^2 C^2 R_2^2}}{\omega C\, R_2} = \frac{\sqrt{1+R_{N2}^2}}{R_{N2}} \quad (6)$$

Where R_{N2} is the human leakage resistance, normalized to the impedance of the capacitance. A plot of the readings k_2, normalized to the readings when the human leakage resistance is infinite, versus the human leakage resistance, normalized to the impedance of the capacitance, is shown in Fig. 3. The increase of the readings due to the human leakage resistance is evident when the normalized human leakage resistance is small than 1. This is the case when the human wear an antistatic shoe and standing on the antistatic floor.

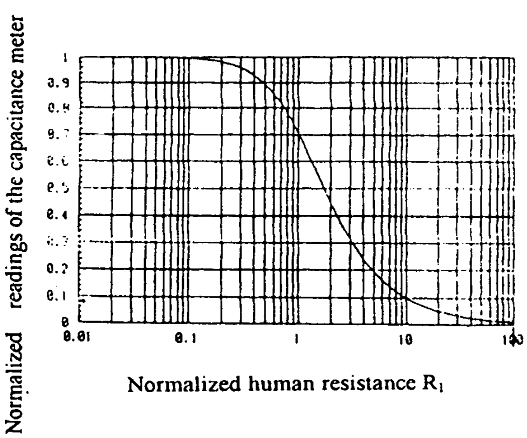

Fig.2 The Effect of the human resistance to the readings of capacitance meter

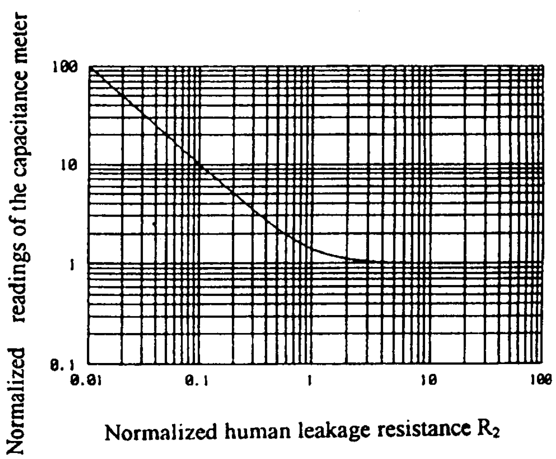

Fig. 3 The Effect of the human leakage resistance to the readings of capacitance meter

I.c. The Effect of the Human Leakage Resistance R_2 and Human Body Resistance R_1 to the Readings of Capacitance Meter

When the human leakage resistance R_2 is not great and the human body resistance R_1 is not small, the readings of the capacitance meter with the two elements is shown in Fig. 4. The readings of the capacitance meter increases as the human resistance R_1 and the human leakage resistance R_2 decreases. The readings of the capacitance meter decreases as the human resistance decreases.

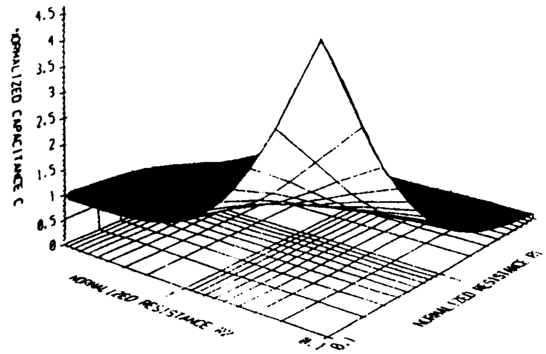

Fig. 4 The effect of the human leakage resistance R_2 and human body resistance R_1 to the readings of capacitance meter

It is easy to observe the value from the 2-D graph than in the 3-D graph. The equal value lines of the normalized readings of the capacitance meter versus the human leakage resistance R_2 and the human body resistance R_1 is shown in Fig.5.

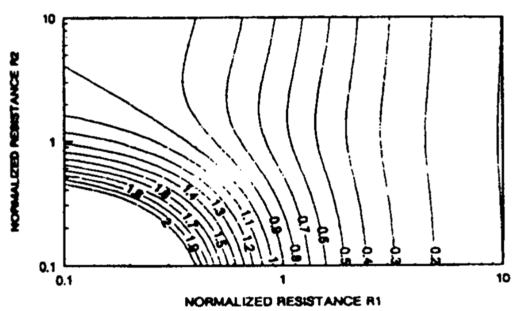

Fig. 5 Equal value lines of normalized readings of the capacitance versus the human leakage resistance R_2 and the human body resistance R_1

II. The Measurement of the Human Body Capacitance

The capacitance between an isolated conductor and the ground is defined as the ratio of charge on the conductor to the potential of conductor. The human body is not conductor but we can also define the human body capacitance in this way. That is, the human body capacitance is equal to the ratio of the charge on the human body to the potential of the human body. The potential of the human body is measured by the electrostatic voltage meter and the charge on the human body is measured by charge meter. An example of the measurement of the human body capacitance is shown in table I and Fig.6. The charge on the human body is linear proportional to the potential of the human body.

$$C = \frac{Q(nC)}{V(kV)}(pF)$$

Table I The Charge on the human body and the potential of the human body

Q(nc)	V (kv)	C=Q/V (pF)
113	1.00	113.0
225	2.00	112.5
337	3.00	112.3

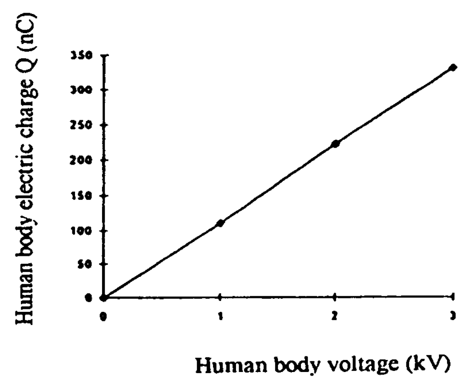

Fig. 6 An example of charge on the human body versus the potential of the human body

III. Conclusion

The human body resistance and the human leakage resistance can influence the readings of conventional capacitance meter greatly when the human body resistance is greater and the human leakage resistance