Indirect Measurements on the Capacity in the Electrostatic HB Model

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***Abstract*-**Considering the classic HBM, for the associated human body capacitance (HBC) is generally accepted the value of 100 pF. Developing a method based on the charge preservation and using the Model 6517A as electrometer, we measured for HBC values spread between 50 and 500 pF. This quasi-large dispersion encouraged us to emit and to experimentally verify assumptions regarding the effective values of the HBC, according to different states, circumstances and accepted models. There is good accordance between measured and expected data. One conclusion might be that the classic HBM is rather a conventional and traditional testing standard than a real world universal circuit.

I. Introduction

A standing human body isolated from ground is in essence an insulated conductor and has a definite capacitance and in consequence, the ability to store a charge and possibly discharge the stored energy in a (spark)discharge, [1].

The Human Body Model is the oldest and best-known ESD model, dating back to the 1800s. Commonly, electrostatic charges are created by the contact and separation of two materials. One of the most common causes of electrostatic damage is the direct transfer of electrostatic charge from the human body to a device, as shown in Figure 1. The sudden release of charges into the device can produce extremely high voltage or current at the device that can results in irreversible transformation and destruction of the circuit or even the whole equipment, [2].

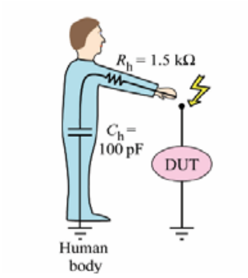

Figure 1. Human body causing an electric discharge on the "device under test" (DUT)

The equivalent electric circuit, which simulates the discharge from a person delivered to the device, is shown in Figure 2. This electrical circuit is called the human body model (HBM) and it is a very commonly used model for testing the equipment sensitivity to ESD. The model has a 100 pF capacitor that discharges through a 1.5 kΩ resistor and a switch into the device under test (DUT), [3]. The value of 100 pF is generally accepted as standard and has been adopted for testing solid state devices, taking into consideration their potential sensitivity to electrostatic discharge, [4].

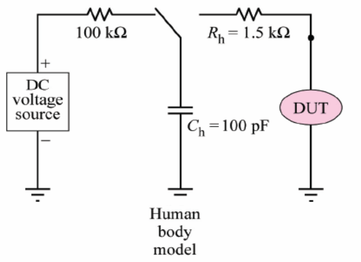

Figure 2. Classical HBM equivalent circuit

II. Indirect measurements of the human electric capacitance

The quintessence of the indirect method is to charge the unknown capacitor at a certain voltage, to conserve the charge, immediately to place in parallel a well-known comparable capacitor and then to measure with an electrometer the so established equilibrium voltage value across the plates.

Trying to implement this approach, we used the coulomb function of the 6517A Programmable Electrometer, [5], covering the Coulombs range from 20 nC to 20 μC, with a resolution from 10 fC to 10 pC. By reason of the huge 200 TΩ input impedance, the charge measurements performed by current integration are inside the interval from 10 fC to 20 μC. Due to the bias current lower than 3 fA, the charge drawn from the measured capacitors or put on them, during a few seconds could be neglected.

For the connections of our experiments, we operated with low noise 3-slot triax cable with adapters to male-female BNC and alligator clips. For charging the human capacity we used the built-in ± programmable voltage source. To enhance the storage and display capabilities by using a note-book, we operated with the RS 232C serial interface.

We designed and manufactured a DC-AC-DC converter. From an adjustable, regulated low voltage power supply (ranging from 1 to 10 volts at up to 1.2 amperes), we supplied an emitter follower connected to the primary of a transformer made by 10 turns on a 4 mH ferrite core inductor. A capacitive divider provides positive feedback to the transistor base, the secondary of the transformer being tuned to about 200 kHz. A hemi-wave voltage twice multiplier produces DC outputs between 100 volts and 1000 volts, with the current capability being of only 1 milliampere, for security reasons.

We experimented with a volunteer standing in the right position but barefoot, on 1 to 4 rubber carpets, each of them having 4 mm thickness, as shown in Figure 3.

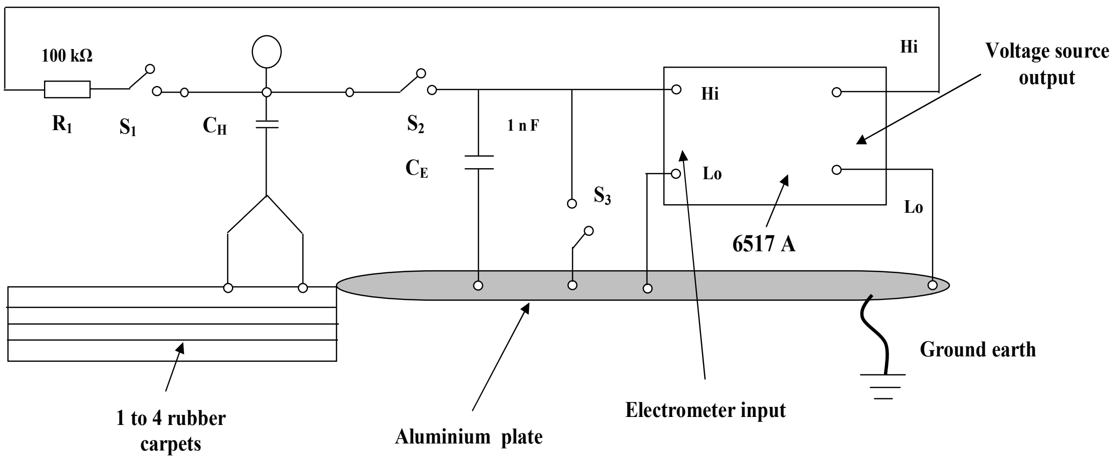

Figure 3. Experimental set-up for indirect measurement of the real human body capacitance, C_H

These one to four rubber carpets have each of them, 2 square meters surface, experience the dielectric constant 2.7 (the relative permittivity, linked to the permittivity of free space, 8.85 pF/m) and in consequence, ensure a safe isolation from the ground earth.

We applied various D.C. voltages to the person, from the built-in source of the electrometer, when S_1 and S_3 are on and S_2 is off, through a protective charge resistor R_1. The electrostatic charge Q could be estimated by using formula (1), where U_K is the precisely-known voltage delivered by the built-in source.

$$C_H = \frac{Q}{U_K} \tag{1}$$

Then, S_1 and S_3 are off and S_2 is on, connecting the capacitance to be measured parallel to a well-known high quality capacitor, C_E = 1 nF. After reaching the equilibrium between the two capacitors placed in parallel, the electrometer measured the potential on them, U_M, allowing us to use formula (2).

$$C_H + C_E = \frac{Q}{U_M} \tag{2}$$

Based on conservation of charge, the capacitance of the human could be determined, by eliminating Q from (1) and (2), as it is expressed in (3).

$$C_H = C_E \frac{U_M}{U_K - U_M} \quad (3)$$

III. Results and interpretation

We did many measurements, progressively using from only one carpet to all four carpets. For the beginning, human was standing in the strict vertical position. Experiments in the same conditions but with the volunteer sitting on a wooden chair (bare feet on the carpet) revealed only an approximate less than 10 pF insignificant increase of the so measured body capacitance.

While standing in knees, but with the feet partially pressed on the carpet, the values of the measured C_H are significantly reduced. The statistical acquired results (mean values) are presented in the Table 1.

	One rubber carpet	Two rubber carpets	Three rubber carpets	Four rubber carpets
C_H (measured human capacitance), vertical	295 pF	178 pF	138 pF	116 pF
C_H (measured human capacitance), sitting	287 pF	165 pF	124 pF	105 pF
C_H (measured human capacitance),in knees	295 pF	165 pF	121 pF	101 pF

Table 1. Measured capacitance versus the thickness of the isolation

At a first glance, we see big differences between the generally accepted 100 pF value and the measured ones. We try to find an explanation, in accordance with the previously obtained results. We can assume that the measured capacitance is composed from two main capacitances in parallel connection. One of them is acquired by regarding the human body as if it were comparable to an isolated sphere, [6]. The use and acceptance of a 100 pF capacitor as a standard to simulate the human body behaviour from capacitive point of view was initially established starting from the capacitance of an isolated sphere.

The potential of an isolated sphere is given by :

$$V_{sf} = \frac{Q}{2\pi\varepsilon D_{sf}} \quad (4)$$

where D_{sf} is the diameter of the sphere. When assimilating the isolated human with an isolated sphere, D_{sf} means the average human stature (175 cm).

Defining the capacitance as the ratio between the charge on one electrode and the potential difference between the electrodes, we have:

$$C = \frac{Q}{V} \quad (5)$$

The potential difference established between two concentric spheres (a smaller with D_{sf} diameter inside and a larger one, with D_{ext} diameter) was deduced by applying Gauss's Law to a single spherical shell of charge:

$$V_{sf} - V_{ext} = \frac{Q}{2\pi\varepsilon}\left(\frac{1}{D_{sf}} - \frac{1}{D_{ext}}\right) \quad (6)$$

By assuming the actually isolated sphere, the surrounding objects have to be located at infinity. In consequence, the theoretic capacitance of a human approximated by a completely isolated sphere is:

$$C_H = C_{sf} = \frac{Q}{V_{sf}} = 2\pi\varepsilon D_{sf} \quad (7)$$

In free space, ε is 8,85 pF/m, and for a medium tall person, the value is about 97 pF, naturally being approximated at 100 pF.

The second capacitance is obtained by treating the standing human (quasi-good conductor) as one plate of a parallel capacitor and ground-earth as the other plate. This second capacitance, located between the body and ground has as most usual dielectric, the footwear (shoe sole) and/or the floor covering. Under the infinite plate hypothesis, the correlation between the charge Q and the field E among the plates is, [7]:

$$Q = \varepsilon E S \tag{8}$$

Really we have a half-isolated human modelled as a conductive plate placed near a second object located at well defined distance *d*. This second object is the only other object to be taken into consideration, having the potential zero (reference potential of this set-up). In consequence, the human body potential for the flat parallel plate model is:

$$V_p = \frac{Q}{\varepsilon S} d \tag{9}$$

where *S* is the effective flat area of the human body, separated from the next nearby and flat object by the distance *d* and ε being the permittivity of the material between these plane objects.
Using equation (5), we obtain:

$$C_p = \frac{\varepsilon S}{d} \tag{10}$$

Trying to harmonize the theory with experimental results shown in Table 1, we observed that the decreasing of the measured capacity is not proportional to the increasing of the isolation thickness. It is the proof that total human capacitance is the sum of two terms: C_{sf}, independent of the isolation parameters but influenced by the tallness of the subject and C_p deeply dependant (thickness and the dielectric constant) by the isolation between the subject and the ground earth.

Considering the data from the first row of Table 1 (vertical position), we calculate in a system with 2 equation and two unknown data:

$$\begin{cases} 295 = C_{sf} + C_p \\ 178 = C_{sf} + \dfrac{C_p}{2} \end{cases} \tag{11}$$

The obtained values are 234 pF for C_p and 61 pF for C_{sf}, values that verifies the following two acquired data, noted in the remaining cells of the first row

Similarly considering the data from the second row of table one (sitting on a wooden chair), we obtained 245 pF for C_p and 42 pF for C_{sf}, also in acceptable accordance with other data attained in the same settlement.

By processing the data from the third row, (sitting in knees on the floor), we obtained 260 pF for C_p and only 35 pF for C_{sf},

IV. Conclusions

As the thickness of the insulated material increased, the measured capacitance decreased until a value around 105 pF was reached. From these measurements as well as the analysis presented here we can conclude that in most real world situations, the sum presented in Equations (11) has C_p as dominant term for a person standing on a floor or sitting in a chair, whereas C_{Sf} may be dominant for a person in a shielded space, where the reference plane closely surrounds the entire human body.

Acknowledgements

This work was financed and developed in the framework of the RTD National Program CEEX, financed by Romanian Authority for Scientific Research, the grants P-CONFORM CEEX-M4-3885, "Laboratory for Immunity Tests at Electrostatic Discharges" and P-INT-VIZ CEEX-M3-12335, "Support for the Integration of Romanian Research in the Field of Electromagnetic Pollution".

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