Measurements upon Human Body Capacitance: Theory and Experimental Setup

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Abstract- This paper proposes a method to estimate the value of the Human Body Capacitance, by direct measuring it, with an experimental setup based on 6517A model. More accurate and stable results are obtained when improving the setup with a Faraday cage. There is offered a pertinent and sustainable by practical results explanation for the reduced measured value of the bulk capacitance of the Human body considered as a fully isolated sphere.

I. Introduction

One of the daily human interactions with the environment is the capacitive one, when the body must be considered as intrinsic part of an electrical circuit. It is told that the fourth property of the human body is its capacitance. The word "capacitance" extracts its origin from the word "capacity", meaning the capacity of that object to hold electrons and, in consequence, to store charges. A capacitor is a device for storing electrical charge and due to this biological property of the human body, its behaviour is that of a good capacitor being able to store significant electrical charge. This is taken into consideration when designing touch switches, nearness detectors, various ESD models or even antennas for radio devices acting in the human neighbourhood.

Most of the actions involved by correct ESD management are based on a realistic approximation of the capacitance of the human body. These precautions receive nowadays high importance as the great majority of electric devices are equipped with high-speed, low-power ICs, [1], extremely vulnerable to electrostatic discharge (ESD). As ESD is frequently generated by human presence and action, the ESD generating mechanism must be well understood and the associated capacitance must be correctly evaluated.

Due to so many salty fluids, the human body has conductive properties and, therefore, has a capacitance which could store electrical energy with respect to its surroundings, [2], such as the floor, the walls or other people.

II. Starting point

Various measurements performed in our Electrostatics Laboratory upon the values in the real world of human body capacitance, revealed a quite large dispersion of the results, in a large neighbourhood of 100 pF, the C_{stray} value of the typical HBM equivalent circuit. There were significant differences with the body position (vertical, chair sitting or even laid on horizontal position) and with the position of the arms (at right angle or near the body), [3]. A reasonable attempt was to "split" the classic capacity in two: one C_{bulk} of the main body and the other C_{arm} for the hands and the arms, both of them with respect to the surroundings, as modelled in Figure 1.

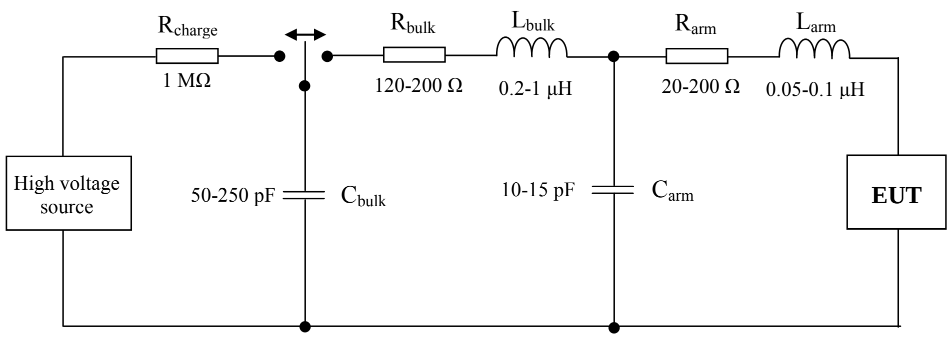

Figure 1. Detailed model of body behaviour while discharging on sensitive equipment

The capacitance is one of body's features, being influenced not only by the weight and height of the individual but also by posture, relative position and closeness to other electrically conducting elements or by the type (or lack) of motion. So, as any other human attribute, the capacity is influenced by the environment and its characteristics, [4].

One of the experienced setup is presented in Figure 2, in order to direct measuring the total HBC, by using the Model 6517A in Coulomb mode, [5], with the built-in step voltage source. As we can see in the figure, the human is connected in series with the electrometer and the charging source.

In some previous experiments we did not have the Model 6517A, but a simpler one, 6514. To obtain step high voltages, 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 one milliampere, mainly for security reasons. One voltmeter indicates the output voltage on the charging BNC connector (most usual 200 volts), while a second meter, connected in series to the charging point, acts both as a current meter and as a limiting resistor. We use a grounding switch serving to activate the relay that drains the electrometer input, thus resetting the meter to zero.

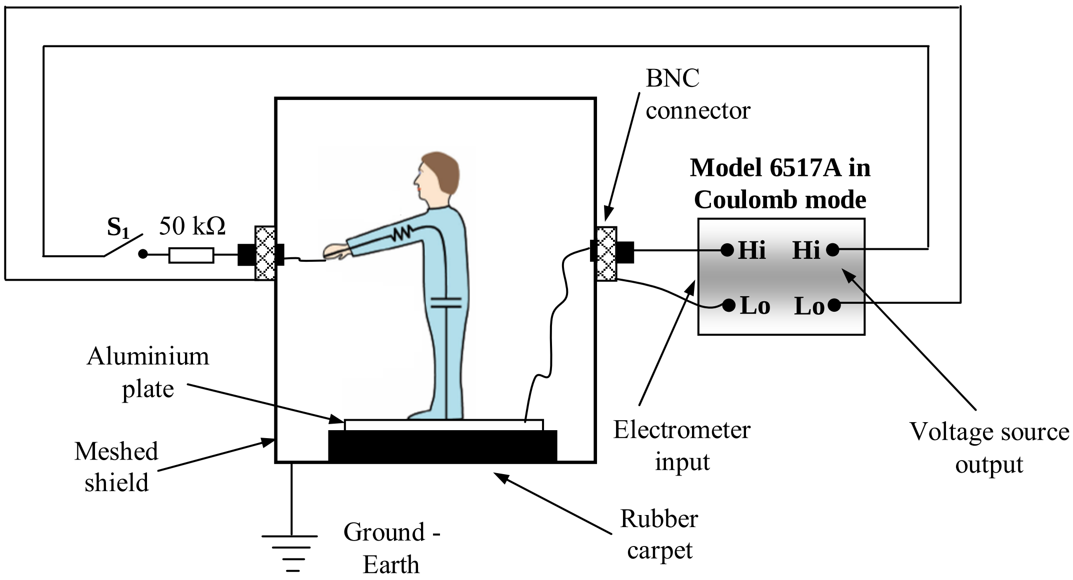

Figure 2. Experimental set-up for direct measuring the HBC

Before switching on S_1, it is necessary to disable the electrometer's zero check and suppress the reading. When S_1 is off, the charge should be read as fast as possible. After saving the result, it is mandatory to reset the voltage source to 0 V and in consequence, to dissipate the accumulated charge.

We provided for this experiment a meshed shield, connected to the Low input terminal of the electrometer. The human is staying straight vertical or sitting on a chair with bare feet on the Aluminium sheet, isolated from the shield with a thick rubber carpet (12 mm thickness).The acquired results are presented in Table 1.

	Charging voltage (V)	100	150	200	250	300
Vertical position	Measured Q(nC)	21	30	36	37	39
	Calculated C(pF)	210	195	178	147	130
Sitting on chair	Measured Q (nC)	19	27	33	34	36
	Calculated C(pF)	190	182	163	135	119

Table 1. Measured capacitance versus charging voltage and human position

Knowing the charging voltage, measuring the stored charge, we compute the equivalent capacity with formula:

$$C = \frac{Q_{fin} - Q_{in}}{V_{fin} - V_{in}}, \quad (1)$$

in words, the ratio between the gradient of charge and voltage potential. As we can see, there were registered differences between the accumulations of charge when applying the same voltage to the same human staying in different positions. These could be explained by the height decrease and the surface increase when sitting, with other words, one of the parallel capacitor decreases while the other increases.

III. Improved experimental setup

Wanting to obtain zero electric disturbing (atmospheric or stray) field in the nearby of the charged human, we improve the previous arrangement by manufacturing, from Aluminium mesh a Faraday cage. This development let us measuring the charge more accurately. We have two shields, one inside the other. The inside shield is connected to the electrometer High input while the outside shield is connected to the electrometer Low input. After charging the human, S_1 is off and all the charge will flow into the electrometer. We have chosen for the shields the cylindrical shape, quasi-simple de manufacture. For the support insulator we used a thick ceramic floor. For connecting the inner shield to the electrometer input, a BNC to triax adapter is the best solution.

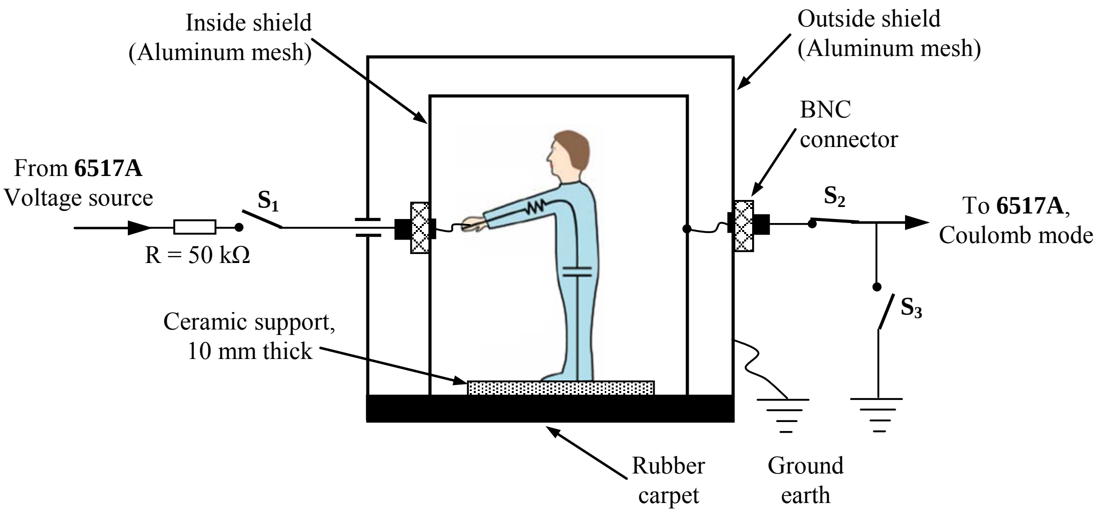

Figure 3. Experimental set-up involving Faraday's cup for indirect measurement of the real human body capacitance, C_H

The so obtained results presented in Table 2 are more stable versus the charging voltage variations and are lower comparing to the previous values because the Faraday cup eliminates all the disturbing electric fields.

	Charging voltage (V)	100	150	200	250	300
Vertical position	Measured Q(nC)	17	25.2	33.2	40.5	48
	Calculated C(pF)	170	168	166	162	160
Sitting on chair	Measured Q(nC)	16.5	24.5	32.6	40	47.7
	Calculated C(pF)	165	164	163	160	159

Table 2. Measured capacitance versus charging voltage and human position inside a Faraday cage

IV. Capacitance of an isolated (hemi)sphere

The closest to the real world situation seams to be the acceptance that the human body capacitance (HBC) is composed from the capacitance of an isolated sphere in parallel with a group of well-specified parallel capacitances, [6]. The radius of the conventional sphere could be determined by estimating the total surface area of the specific human body under study and equating this area to the area of the equivalent spherical human body. Based on equivalent surface area the average grownup will have an isolated sphere capacitance C_{Sp} typically in the range between 40 pF and 50 pF, [7].

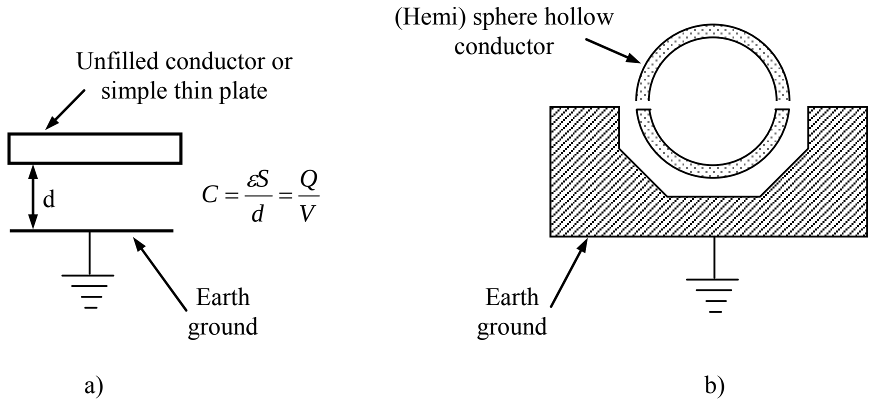

Figure 4. Only half of the surface is close to the ground

Why 50 pF and not 100 pF, as estimated by applying the formula of the capacity for a totally isolated sphere? Explanations are affordable by studying Figure 4. In. 4 a). is proved that the capacity of a specific arrangement is the same, no matter the parallel conductors are simple thin sheets or unfilled, hollow conductors. The situation of a hemispherical conductor is shown in Figure 4 b). If we would replace the hemispherical conductor with a sphere we expect that any charge on the sphere to be contained on the lower half of the sphere due to the attraction of opposite charge on the ground. Thus, we can conclude, as long as only half of the sphere's area is exposed to the ground, is expectable that the upper surface of the sphere to contribute little to the capacitance.

V. Conclusions

The dispersion of the results while measuring the C_{stray} value of the typical HBM equivalent circuit received explanations sustained by our measurements. There were significant differences with the body position (vertical, chair sitting or even laid on horizontal position) and with the position of the arms (at right angle or near the body). Wanting to obtain zero electric disturbing (atmospheric or stray) field in the nearby of the charged human, we improve the test fixture by manufacturing, from Aluminium mesh a Faraday cage. This development let us measuring the charge more accurately. The so obtained results are lower and more stable versus the charging voltage variations because the Faraday cup eliminates many of the parasitic capacitances.

Acknowledgements

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