Measuring the Body Voltage on Wearers of Category 3 Bunnysuits

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Abstract – The electric field sensitivity of modern photolithographic reticles [1,2] and of magnetoresistive heads [1] is extreme. Many modern semiconductor components have CDM damage thresholds below 100 V and place similar demands in back end fabs and in electronics assembly [4]. Often this requires use of Category 3 [5] cleanroom garments designed to limit body voltage to 100 V [2]. A Charge Plate Monitor (CPM) is specified to measure body voltage [2]. This paper investigates the measurement accuracy. It is shown that the capacitance of measurement system causes the CPM to underestimate the walking voltage.

I. Introduction

Modern photolithographic reticles have an extreme sensitivity to electric fields. The effects of electrostatic discharge [6] (ESD) and electric field migration [6] (EFM) have been documented many times in the literature. In disk drive manufacturing, the magnetoresistive (MR) heads have even greater sensitivity [7]. Also, as chip speeds increase, the feature size becomes smaller and hence the sensitivity to voltage has become severe [8]. Electrostatic damage to any of these components has severe financial consequences.

Bunnysuits for use in the cleanroom are rated as Category 1, 2 or 3 [9]. The first two categories provide a Faraday shield against static charge on the garments or undergarments the wearer wears within the bunnysuit. This paper focuses on Category 3 which also grounds the person within the bunnysuit so that unshielded parts of the person (hands and face) do not present a charge to the objects being handled.

The specifications in S20.20-2014 state that the resistance to ground of the person in the bunnysuit must be <35 MΩ AND the body voltage of the person be less than 100 V peak [10]. The body voltage measurement is specified by ANSI/ESD STM97.2 [6] and employs a CPM as the data acquisition element. This instrument was undoubtedly selected as one common to most facilities dealing with static charge but it has been posited that this instrument may underestimate the walking voltage in some circumstances. This article addresses the measurement technique and compares results to those being measured with an electrostatic voltmeter (ESVM) and with a high impedance digital voltmeter (HIDVM).

II. The CPM vs. the ESVM vs. the HIDVM

The CPM is defined as a non-contacting voltmeter measuring the voltage on an electrically isolated metal plate [1]. This instrument is defined as a 30 cm × 30 cm 20 pF ion-collecting plate with a contacting or non-contacting voltage measuring device and a timer. The plate is used as a reference device for benchmarking the performance of air ionizers. The body voltage is measured by clipping a wire to the plate and having the person in the study hold an electrode which is in electrical contact with the wire. See Figure 1a.

In this case, the electrode in the hand of the person is nothing more than a cylindrical piece of metal.

The electrostatic voltmeter (ESVM) is a more sophisticated instrument as is the high impedance digital voltmeter (HIDVM). See Figures 1b, 1c and 2a, 2b and 2c.

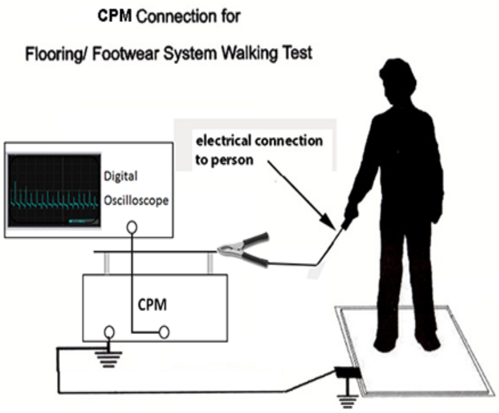

Figure 1a. Using a CPM to measure body voltage.

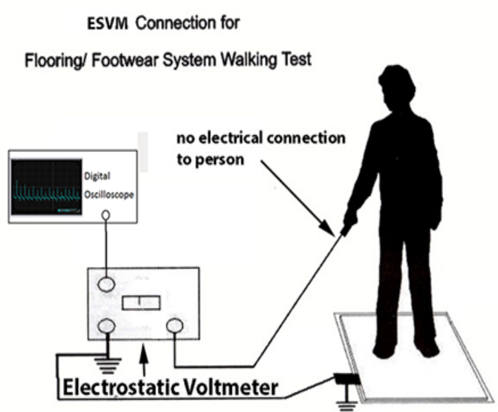

Figure 1b. Using a non contacting electrostatic voltmeter to measure body voltage.

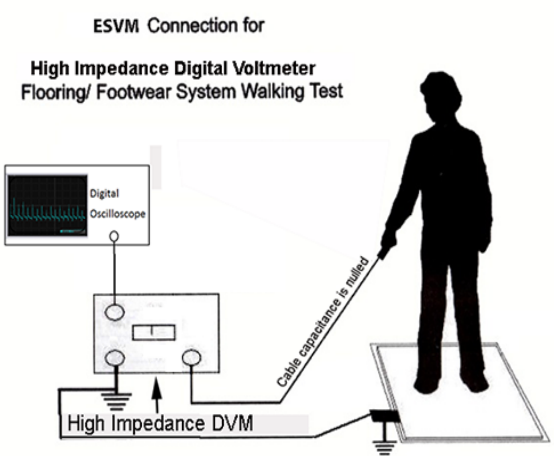

Figure 1c. Figure 1b. Using HIDVM to measure body voltage.

In the ESVM, an electric field sensing element is located on a vibrating reed or behind an oscillating shutter is located within a cylindrical or

The sensor detects an AC modulation current that drives the voltage applied to the enclosure until it equals the voltage on the device under test (DUT). No part of the ESVM makes contact with the DUT so no capacitance is added to the device by the ESVM.

In the case of an ultra-high impedance digital voltmeter, the shield of the cable to the probe from the meter is driven to allow the unit to null the measured voltage. Since the shield and the signal are always at the same potential, the device electronically nulls its own capacitance. A block diagram of an HIDVM is shown in Figure 2c.

Walking voltage with the ESVM is measured by placing the ESVM sensor inside of a metal electrode while taking care to electrically isolate the probe from the ESVM sensor inside. Either ESVM sensor configuration can be used but Trek supplies a walking probe commercially.

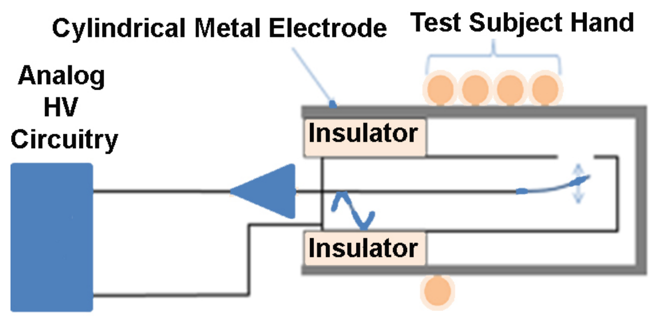

Figure 2. Configuration of walking probe for ESVM.

The fingers of the walking person are shown in Figure 3. The ESVM configuration presents very high impedance and thus no loading to the person, so the voltage should be accurately measured.

Two HIDVMs were also tested: The Trek 821HH (specified at .01 pF loading) and the Prostat CVM780 (specified at 0.1 pF loading).

III. Capacitive Loading

Triboelectric charging takes place as the person in the garment walks along the floor of the cleanroom. Discharge of the person is the result of the resistance to ground of the floor and the distributed capacitance of the cleanroom floor. The latter will not be addressed at this time but is an important effect in understanding the performance of the discharge process for the operator and garment.

As long as the contact force between the boots and the cleanroom floor is consistent and the strides are uniform, the charge delivered to the person through triboelectric charging will be rather consistent. To allow the various measurements to be compared many steps are measured for each instrument and peak voltages per step are averaged.

Take the charge per stride to be an amount, q. In this case, the voltage on the person will be

$$V = q/C_{\text{person}} \qquad (1)$$

Here C_{person} is the capacitance of the person, nominally 100 pF. In the case of a CPM based measurement, however, the total capacitance is that of the person, the interconnect and the CPM. See Figure 4a. In the case of an ESVM or a HIDVM, the charge is not shared with the extra capacitance, see Figure 4b. Therefore, the voltage measured with these devices should be the same voltage as exists on the human body because there are no addition of the instrumental (parasitic) capacitances.

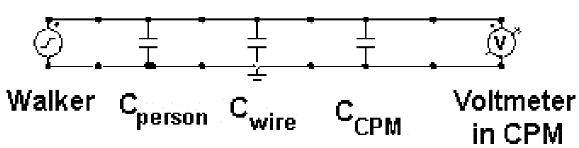

Figure 4a. Equivalent circuit for CPM based measurement

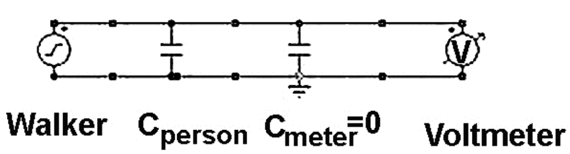

Figure 4b. Equivalent circuit for zero capacitance meter.

In the case of the CPM based measurement, the values of parasitic capacitances are expected to lower

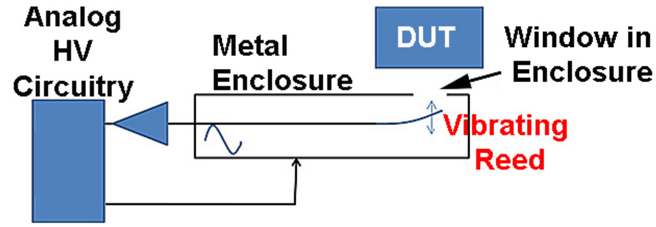

Figure 2a. Vibrating reed sensor.

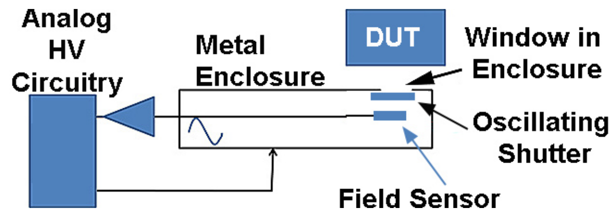

Figure 2b. Oscillating shutter sensor.

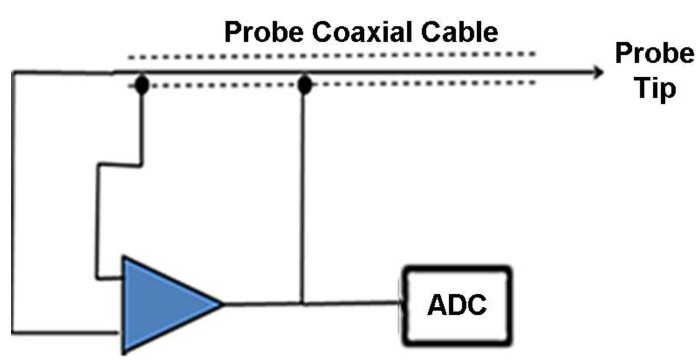

Figure 2c. A high impedance digital voltmeter.

significantly lower the measured body voltage. See Figures 5a, 5b, and 5c.

In the case of the CPM measurement, the actual circuit includes the parasitic capacitance and Equation (1) must be modified to account for this. See Equation (2).

$$V_{\text{CPM}} = q/(C_{\text{person}} + C_{\text{wire}} + C_{\text{CPM}}) \qquad (2)$$

Taking the human body capacitance from the HBM definition document [1]

$$C_{\text{person}} = 100 \text{ pF}$$

This number was confirmed by our measurement of several people.

The capacitance to ground of a 3 m long wire was measured with a capacitance meter and found to be

C_{wire}= 25.5 pF

This was measured using a Tektronix model 130 LC meter and the wire suspended at table height.

Also with the 1.25 m of the wire resting on a ground plane,

C_{wire}= 65 pF

From the specification of a CPM,

C_{CPM}=20 pF

For a measurement with the 3 m wire with no nearby ground plane, the body voltage reading with a CPM is expected to be lower than the measurement shown in Figure 4 by a factor of

$$A = C_{person}/(C_{person} + C_{wire} + C_{CPM}) \quad (3)$$

100 pF/(100 pF + 25.5 pF + 20 pF) = 69%

And if a section of the connecting wire rests on the ground plane, the factor becomes

100 pF/(100 pF + 65 pF + 20 pF) = 54%

or a 46% underestimate! That could represent the difference between safe and in-jeopardy products.

IV. Direct Measurement

Measurements were made with a CPM (a Monroe 288B and a Trek 157) and an electrostatic voltmeter (a Trek 541A) with a side viewing probe and a walking electrode (Figure 3). For data acquisition, a LeCroy LC564A and a Tektronix TPS2014 digital oscilloscope were used. Measurements were also made with two different HIDVMs, a Trek 821HH and a Prostat CVM780.

First, both probes (the ESVM probe and the simple cylinder connected to the CPM plate) were connected together in the two hands of the subject and marching commenced. The waveforms recorded (with the published instrument gains accounted for) were overlaid and found to be identical in amplitude and wave shape. In this case, the voltage being measured by both instruments was the same owing to the electrical connection through the subject (attenuated by the charge sharing factor shown in equation 3). This shows that the calibration of both instruments is consistent.

A good deal of time was spent on developing a reproducible marching scheme using the same foot pattern as the so-called ESD shuffle. Attention had to be paid to the consistency of the cadence and sliding of the footsteps to In the end, it was found that marching could be measured to an accuracy of ±7%! This required that the sample taken was sufficiently long (>1 minute) so that many paces were included and that the walker try to maintain consistent walking.

To demonstrate the interaction of the reading with the parasitics, the CPM and the ESVM were measured at the same time. Half way through the trace, the CPM electrode was dropped and only the ESVM was connected for the remainder of the trace. See Figure 5.

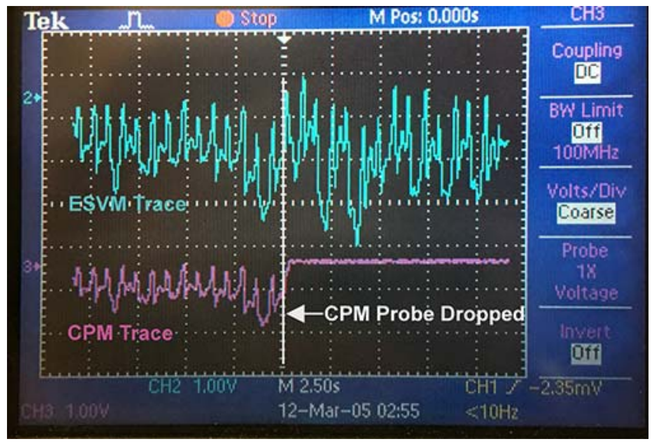

Figure 5. Trek walking test kit vs Trek CPM walking test measurement. The effect of capacitive loading by the CPM is evident.

The scope trace clearly shows a significant increase in walking amplitude on the upper trace when the CPM was out of the circuit (flat line lower trace).

To try to capture the effect of the capacitance quantitatively, two separate measurements of marching voltage recorded with the Trek ESVM are shown in Figures 6 and 7.

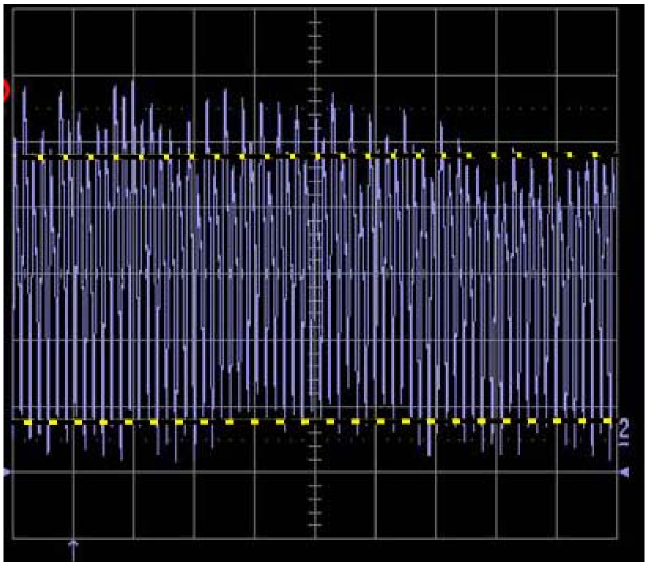

Figure 6. Measuring the walking voltage with the Trek ESVM. Body voltage measured as 79.8 V. Scope settings are 200 mV/div (×100 accounting for ESVM gain) and 5 s/div.

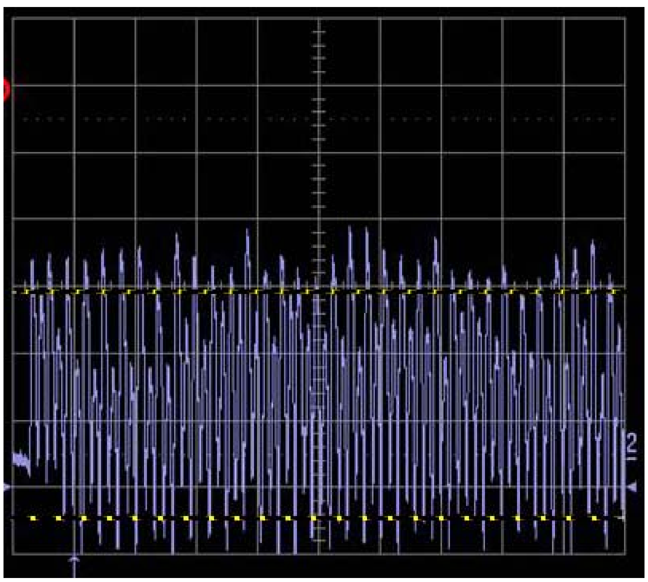

Figure 7. Re measuring the walking voltage with the Trek ESVM to check reproducibility. Body voltage measured as 69 V. Scope settings are identical to Figure 7.

In comparison, the Monroe 288B CPM was used as shown in the configuration recommended by ANSI/ESD STM97.2-2006 shown in Figure 1. A typical data run with this configuration is shown in Figure 8.

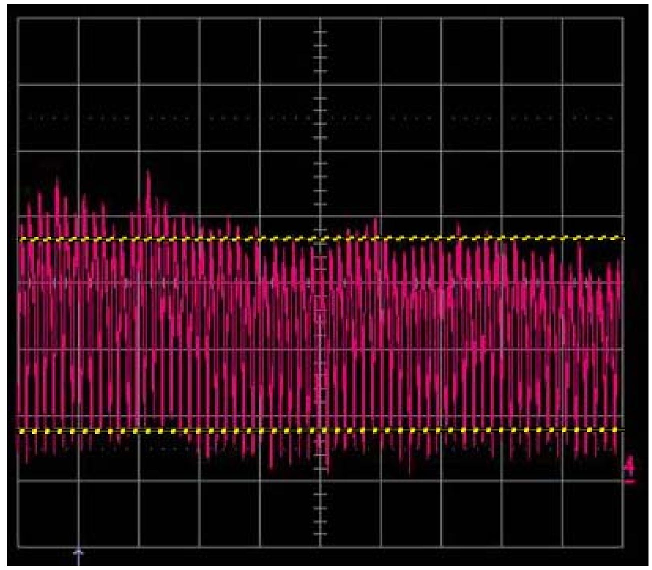

Figure 8 measurement of walking voltage with the CPM with 3 m of wire connecting it to the person. Body voltage measured as 57.4 V. Scope settings are identical to Figure 7. Note, the gain of the CPM output is 200:1 as compared to the ESVM at 100:1.

Finally, the CPM with 3 m of wire and 125 cm of the wire being routed along a ground plane is shown in Figure 9.

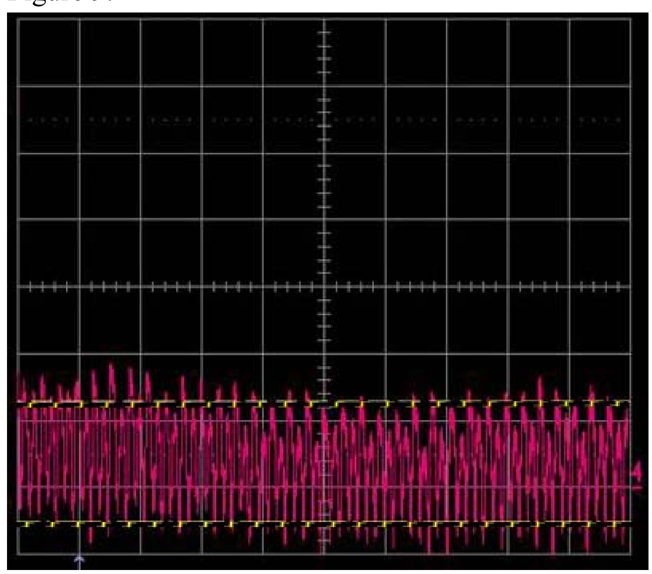

Figure 9. CPM measurement of body voltage with 125 cm of the connection lead on a ground plane. Scope settings are 200 mV/div and 5 s/div. Body voltage = 36 V.

The two HIDVMs (Prostat and Trek) were compared to the ESVM using the same technique involving dropping the HIDVM probe in the middle of the trace. Figure 10 shows the result for the Trek probe. The Prostat HIDVM was used with a simple RC filter, it gave acceptable results. For both HIDVMs, no amplitude loss is seen.

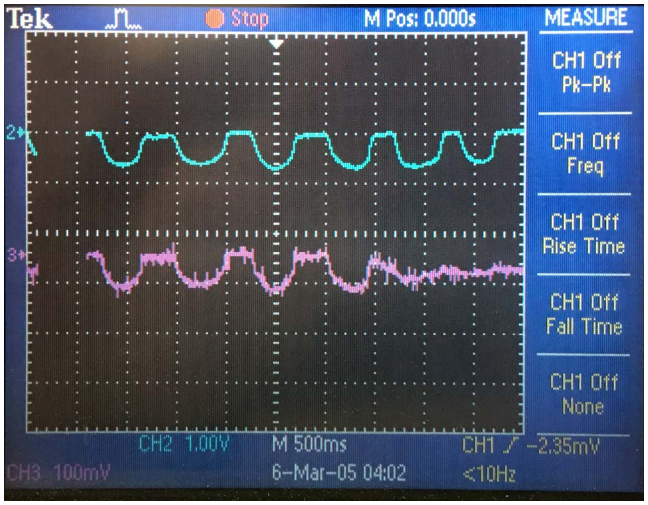

Figure 10. Walking voltage comparison of ESVM (upper trace) vs Trek HIDVM.

V. Conclusions

The results for the CPM vs the ESVM are summarized in Table 1. There is no doubt that the CPM presents a systematic error by under estimating the body voltage. Underestimation is in the range 25 –50% depending upon the length of the wire and how close to a ground the wire is run.

Configuration	Body Voltage	Uncertainty	Units
ESVM	74	±-5.4	V
CPM + 3 m of wire	57	±-4	V
CPM +3 m & 1.25 m proximity to gnd	36	±-2.5	V

Table 1. Summary of measurements

The measurements are well in line with the calculations as shown in Table 2:

Configuration	Predicted underestimate	Actual	Uncertainty
CPM + 9 m of wire	77%	69%	+/-5%
CPM +9 m & 1.25 m proximity to gnd	49%	54%	+/-4%

Table 2. Summary of results

The data showing the comparison of the ESVM to the HIDVM shows that the high impedance voltmeter is also a good choice for the measurement.

It has been shown that the CPM technique underestimates the body voltage and relying on it could put products in jeopardy. At very least, it is recommended that wire lengths be limited to 1 m with care to keep them away from a ground plane. Still, this results in an underestimate of 20% and a safe margin would be to set the limit for body voltage to 80 V rather than 100 V.

The most conservative procedure is to use an ESVM instead of a CPM. That is the recommendation of this paper.

References

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[6] ibid 1, 2.

[7] ibid 3.

[8] ibid 4.

[9] ibid 5.

[10] ibid 6.

[11] ANSI/ESDA STM97.2, page 8, Electrostatic Discharge Association, 7900 Turin Rd. Bldg. 3, Rome NY. 13440.