

## MEASUREMENTS TO ENSURE EFFECTIVE STATIC PROTECTION

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### 1. INTRODUCTION

It is now well established that electronic devices and systems can be damaged by exposure to high electric fields as well as by direct electrostatic discharges to the pins. While good circuit layout and on-board protection may reduce the risk of damage by such events, the only safe action at present is to ensure that devices are not exposed to levels of static electricity above a critical threshold. In BS 5783: 1984 a safe level is deemed to be a potential of 50V adjacent to the device. This low level of static can be achieved by instituting a Static Control Programme which usually involves setting up a Special Handling Area (SHA) in which personnel are correctly earthed and all materials e. g. flooring, bench tops etc. meet the specifications laid down for conductive and static-dissipative materials. However, setting up a SHA does not of itself guarantee a low static environment. Production procedures may change, new materials may be introduced, the performance of older materials may degrade and so on.

To ensure the effectiveness of any static control programme it is important that regular measurements should be carried out:

- (a) to determine the sensitivity to ESD of the devices being produced or handled.
- (b) to confirm that static levels are lower than the critical level, and that new or modified work practices have not introduced high static levels.
- (c) to ensure that both new and existing materials in the SHA meet the necessary specifications for conductive and static dissipative materials.

Only after an 'operational baseline' has been established by regular auditing will it become possible to identify the origin of unexpected problems arising from the presence of static.

### 2. ESTABLISHING THE SENSITIVITY OF DEVICES

Electrostatic discharges direct from personnel to the pins of a device are still the most likely cause of ESD failures. Consequently, the instrumentation available for testing the sensitivity of devices to ESD attempt to simulate such discharges.

The most widely used test circuit is the so-call Human Body Models which, in its simplest form, is shown in Figure 1. The capacitor,  $C_b$ , represents the capacitance associated with the human body while the resistance  $R_b$  represents the skin resistance.

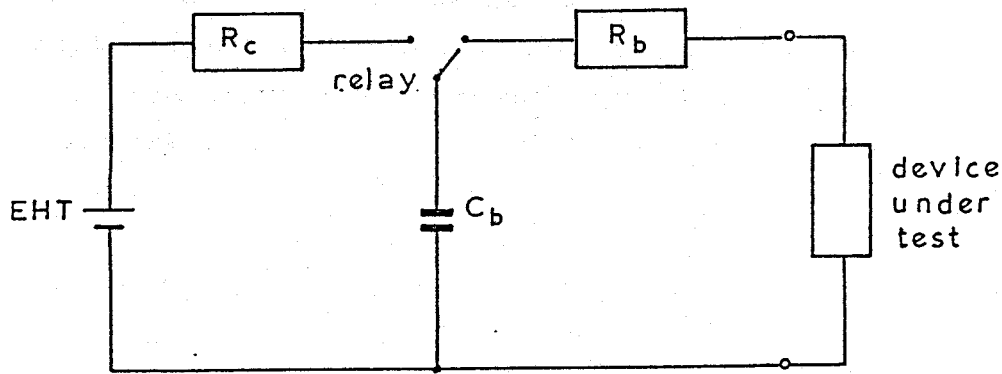


Fig. 1 Simplified circuit used for stimulating human-body ESD transients.  $C_b$  and  $R_b$  represent the body capacitance and resistance respectively while  $R_c$  is a resistance to control the charging current when  $C_b$  is connected to EHT.

During a test, the capacitor is charged to a predetermined value and the switch thrown so that the capacitor is connected to the pin to be examined. The pin is subjected to increasing voltages until damage is recorded, usually by noting changes in the I-V characteristics of the input. The effect of exposure to multiple subcritical ESD events can be determined by setting the voltage at a level below the maximum reached in the previous test and then subjecting the device to repetitive pulses until damage is observed.

Some debate exists over the values to be used for the circuit components in Figure 1, especially since discharges from personnel will not display the same smooth single pulse generated in the simulation. However, despite its limitations the Human Body Model in which  $C_b = 150 \text{ pF}$  and  $R_b = 150 \Omega$  or  $1.5 \text{ k}\Omega$  is widely used and is a valid test method that has provided important information on the effectiveness of protection circuits in ICs<sup>2</sup>.

The same circuit may be used to simulate the effects of electrostatic discharges from personnel to the case or keyboard of electronic systems such as desk top computers<sup>3</sup>. The effect of discharges to the grounded surface on which the keyboard rests has also been investigated.

3.

### MEASURING STATIC CHARGE, ELECTRIC FIELD AND POTENTIAL

Measuring electrostatic quantities poses rather special problems because electrostatic systems are generally characterised by high resistances and small amounts of electrical charge; the latter being true despite the dramatic effects often associated with static. Consequently, conventional electronic instrumentation cannot normally be used.

#### (a) Electric Field

Wherever electrostatic charges accumulate they can be detected by the presence of an associated electric field. The magnitude of this field is determined by many factors e.

g. the magnitude and spatial distribution of the charge, the geometry and location of earthed surfaces and also the medium in which the charge is located. Normally this medium is air, so that if the electric field in the vicinity of the charge exceeds  $\cong 3 \times 10^6 \text{ V/m}$  an electrical discharge will occur.

There are a number of possible ways of measuring electric fields, mostly based on the fact that an electric field will induce a charge on an earthed metal plate. The simplest is an induction probe<sup>4</sup> connected to a high input impedance amplifier which forms the basis of a number of small, relatively inexpensive instruments. The sensitivity and stability is governed by the quality of the FET amplifier which measures the charge induced on the probe and is generally not good enough to measure the low values of electric fields that must be measured in a SHA. The amplifier also has a relatively short time constant and this coupled to the need for frequent zeroing means that the instrument is best suited to measuring changing electric fields such as would occur if a charged person approached the probe.

The most versatile instrument for field measurements is probably the rotating-vane fieldmeter<sup>5</sup> or 'fieldmill' shown in Figure 2. The sensing plate, which is connected to earth through an impedance,  $Z$ , is repeatedly exposed to and screened from the unknown electric field,  $E$ , by the rotation of the rotor vanes. In response to this action an induced charge flows to and from the sensing plate. This induced charge must flow through the impedance,  $Z$ , generating an alternating signal  $V(t)$  across it. When the signal is amplified and rectified a DC output is obtained which is directly proportional to the electric field,  $E$ . Range change facilities are easily incorporated by changing the input capacitance of the instrument and sensitivities from 10 to  $10^6 \text{ V/m}$  are readily achievable. Incorporating a phase sensitive detector allows the polarity of the field as well as its magnitude to be determined.

The fieldmeter is relatively insensitive to atmospheric conditions and electronic problems such as amplifier drift because the field chopping frequency is sufficiently high to produce an alternating induced current of much higher magnitude than any collected atmospheric ion current or other drift currents.

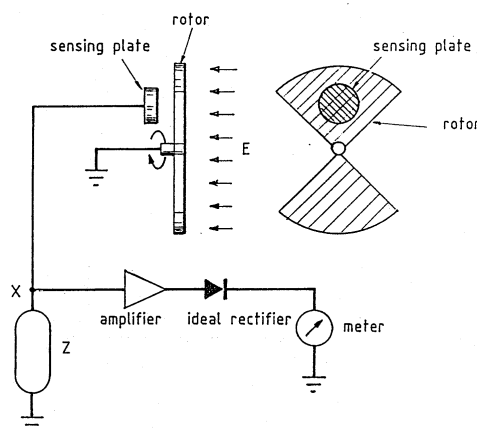


Fig. 2 Elementary Fieldmill

Figure 3 highlights some of the problems that can arise when making measurements of electric field. Figure 3(a) shows a uniformly charged sheet suspended in air, well away from any earthed surfaces. From Maxwell's equations, the electric field normal to the plane of the sheet is given by

$$E = \sigma / 2\epsilon_0 \quad (1)$$

Where  $\epsilon_0$  is the permittivity of free space ( $8.85 \times 10^{-12} \text{F/m}$ ) and  $\sigma$  the Charge per unit area of the sheet and includes charges in the bulk of the film as well as on its two surfaces. The factor 2 appears because the field lines emanate equally from either side of the sheet. When the meter is brought near, all the field lines in the vicinity of the earthed meter are diverted to it as shown in Fig 3(b), so that the measured field will actually be given by

$$E = \sigma / \epsilon_0 \quad (2)$$

An important principle is highlighted here, namely that when a measuring instrument is introduced into an electric field, it invariably changes that field. Furthermore, even equation (2) is not strictly valid for the example in Figure 3(b) because the presence

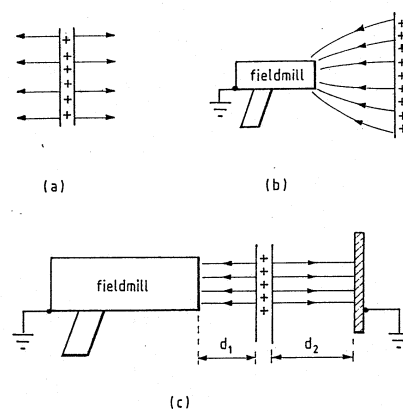


Fig. 3 Electric fields in the vicinity of (a) a freely suspended, uniformly charged sheet, (b) the same sheet near a fieldmeter and (c) the same sheet located between a fieldmeter and a ground plane

of the meter causes field lines to concentrate at the sensing head and so a correction is required. This problem is eased somewhat by means of a guard plate attached to the sensing head.

A much more severe problem with interpreting fieldmeter readings is the effect that nearby earthed boundaries (including personnel) have on the readings. This is so because field lines emanating from electrostatic charges always seek out an earthed boundary. Thus, when an earthed conducting plate is brought up behind the charged sheet of the previous example, see Figure 3(c), the reading on the fieldmeter falls because electric field lines are diverted from the instrument to the plate. It is easily shown theoretically that in this case

$$E = (\sigma / \epsilon_0) [d_2 / (d_1 + d_2)] \quad (3)$$

where  $d_1$  and  $d_2$  are the distance of the sheet from the meter and the conducting plate respectively. Therefore, considerable care is required when making fieldmeter measurements in confined spaces.

(b) Potential

The potential,  $V$ , of an extensive, uniformly charged surface may be determined by measuring the electric field,  $E$ , emanating from the charged surface. If the sensing head is located a distance,  $d$ , in the range 20 to 70mm from the surface then, to an accuracy of  $\pm 5\%$

$$V = E \cdot d$$

Local space potentials may be determined by placing an earthed fieldmeter at the place of interest and noting the field reading obtained. The local potential before the meter was introduced is given approximately by

$$V = E \cdot D$$

where  $D$  is the diameter of the aperture in the sensing head of the meter.

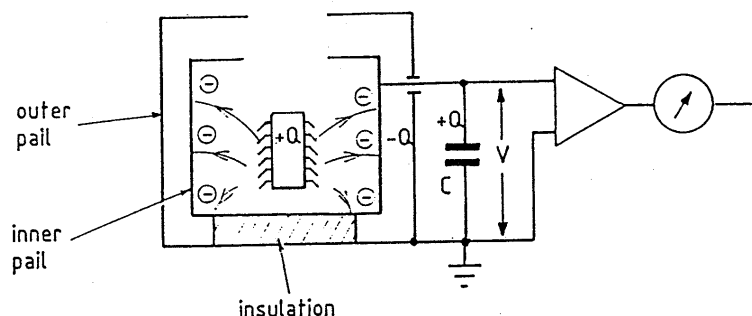
(c) Charge

Occasionally it may be necessary to determine the absolute charge generated on devices during automatic handling. The easiest method is to send the device through the section of handler which is of interest and then drop it into a Faraday Pail as shown in Figure 4. The Pail is in fact two pails, one located inside the other but electrically insulated from it. The outer pail is earthed to provide screening from electrical noise sources e. g. mains hum or other charged objects such as the experimenter!

If the device has a charge  $+Q$ , say, then it induces a charge  $-Q$  on the inside surface of the inner pail. This charge originates from the upper plate of capacitor,  $C$ , which charges to a potential,  $V$ , given by

$$V = Q/C$$

The voltage,  $V$ , may be measured accurately using a high input impedance amplifier, thus allowing the magnitude and 'sign of the charge to be determined.



*Fig. 4 Faraday Pail for absolute charge measurement*

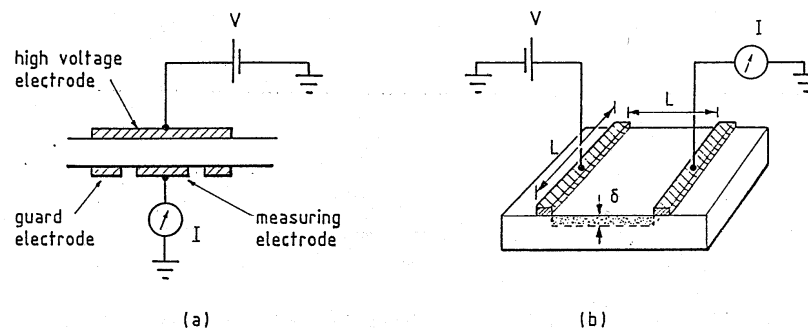
When high accuracy is required, the pail should have a lid, to ensure that the charged object is totally surrounded and that all field lines emanating from it are 'captured' by the pail. It is necessary also to ensure that the capacitances of the pail and the connecting cable are small compared with,  $C$ , otherwise they must be accounted for. Faraday Pails may also be purchased as accessories to fieldmeters. The fieldmeter is located in an aperture in the base of the outer pail so that it can measure the potential of the inner pail, which is directly proportional to the charge enclosed. Once the charge generated on a device during automatic handling is known, then, assuming the capacitance presented by the device can be measured, it becomes possible to calculate the maximum potential developed on it.

#### 4. TESTING THE STATIC DISSIPATIVE PROPERTIES OF MATERIALS

At present, materials to be used in an SHA are generally specified by their bulk electrical resistivity or their surface resistivity. However, there is much interest and pressure for developing a new standard based on measuring directly the ability of a material to dissipate static charge. In this section a brief description of the available measurement methods will be given together, with some discussion of the main problems encountered when making the measurements.

##### (a) Bulk Resistivity

The bulk resistivity of a material is defined as the resistance that would be presented between opposite faces of a cube of side 1m of the material. Of course, it is not practical generally to measure such a large sample. Instead, a manageable quantity, preferably in the form of a slab or film, is sandwiched between two electrodes (Figure 5(a)). A voltage is supplied to the upper electrode and the current through the sample is measured with an electrometer connected to the measuring electrode. For high accuracy, this electrode should be



*Fig. 5 Typical electrode arrangements for measuring (a) bulk resistivity and (b) surface resistivity of static dissipative and insulating materials.*

surrounded by an earthed guard electrode to prevent surface currents being measured. If a current,  $I$ , flows when a voltage,  $V$ , is applied then the resistance of the sample is equal to  $V/I$ . If the sample thickness is  $t$  and the area of the measuring electrode is  $A$ , then the bulk resistivity,  $\rho$ , of the material is given by

$$\rho = RA/t \quad (4)$$

and is quoted in  $\Omega\text{m}$ . The inverse of resistivity is the conductivity which is quoted in Siemens. Electrostatic problems are usually associated with materials that possess resistivities greater than  $10^9\Omega\text{m}$ . If  $\rho$  is less than  $10^6\Omega\text{m}$  the material is unlikely to present an electrostatic-problem.

#### (b) Surface Resistivity

Film materials and laminates are often characterised by a surface resistivity,  $R_s$ , it is defined as the resistance between a pair of electrodes placed on opposite sides of an imaginary square on the surface of the material. In theory, the size of the square is immaterial (so long as the resistivity is not field-dependent). This can be deduced by considering Figure 5(b). Here it is assumed that in response to a voltage applied across a pair of electrodes, of length  $L$ , separated by a distance,  $L$ , a current,  $I$ , flows through a thin surface layer of the material of thickness,  $\delta$ , and width  $L$ . The resistance presented by this layer can be determined from equation (4) and is given by

$$R_s = \rho t/A = \rho L/\delta L = \rho/\delta$$

which clearly is independent of  $L$ . In practice, the measurement is carried out between two concentric electrodes and appropriate corrections made. Surface resistivity is quoted in  $\Omega/\text{square}$  and materials with values in excess of  $10^{10}\Omega/\text{square}$  are the most likely to give rise to electrostatic problems. If  $R_s < 10^5\Omega/\text{square}$  the material is considered conductive.

Several problems will be encountered when making bulk and surface resistivity measurements, particularly on insulating materials and those in the top half of the static-dissipative range. One of the first difficulties to be encountered will be that the current through these materials will decrease for many hours after applying a steady voltage, making it difficult to determine the resistivity unambiguously. Also, most of the materials under consideration will have a resistivity which depends on the magnitude of the electric field to which they are subjected in the measurement. In some instances this dependence may arise from interfacial effects at the electrode. Furthermore, the resistivity of insulating materials is a strong function of temperature, following a law of the type

$$\rho = \rho_0 \exp(U/kT)$$

where  $\rho_0$  is a constant,  $U$  is an activation energy,  $k$  is Boltzmann's constant and  $T$  the absolute temperature. Therefore, if  $T$  increases, the resistivity will fall rapidly.

Resistivity will also be a strong function of humidity; the surface resistivity because of adsorbed water on the material surface, and the bulk resistivity because of

absorption of moisture. Consequently, it may be necessary to condition samples under well-specified environmental conditions before reproducible, accurate measurements can be made.

### (c) Charge Relaxation Time

When charge dissipates from a material it is generally assumed to do so following an equation of the form

$$Q(t) = Q_0 \exp(-t/\tau) \quad (5)$$

where  $Q_0$  is the initial magnitude of the charge,  $Q(t)$  its magnitude after time  $t$  and  $\tau$  is a constant known as the relaxation time. In the simplest theory  $\tau$  is given by the product of the bulk resistivity and the permittivity of the material but will be modified by the geometry of the system being investigated and will also be different if dissipation is via surface processes only.

Many papers have now been published which show that for many static dissipative and virtually all insulating materials the decay of static charge does not follow equation (5). This is so because of the problems raised above concerning the effects of field dependent resistivity, contact effects and composition of the material under consideration. Therefore, it is not possible to predict from resistivity measurements, except in a general way, how charge will behave on the surface of a material.

However, instruments are now available which attempt to simulate the behaviour of charge on a surface so that the dissipative properties of the surface can be measured directly.

Figure 6 shows an example of such a Charge Decay Meter<sup>6</sup>. In this instrument the surface is charged via an isolated metal electrode resting on its surface. A predetermined voltage is applied to this surface electrode by momentarily connecting it to a HT supply using a relay. When the

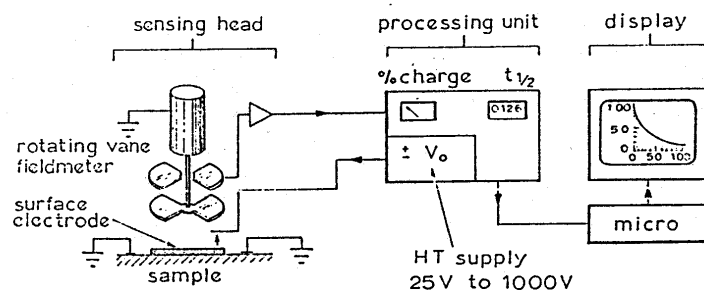


Fig. 6 Schematic outline of the charge decay meter.

charged electrode is isolated, its potential will decay by charge transport through the sample under test or along its surface, or because of polarisation within the insulator. The potential of the electrode is monitored using a fieldmeter for charge decay times in excess of 0.5s or using an induction probe for shorter times. Using such an instrument an interesting range of behaviour has been noted for various materials<sup>6</sup>.



## 5. CONCLUSIONS

Measurements should form an integral part of any static control programme. High quality instruments are available commercially for measuring all the parameters necessary for quantifying the extent of a static problem as well for characterising the properties of staticdissipative materials. Hopefully, the foregoing has provided an introduction to the techniques most commonly used. It is by no means an exhaustive treatment.

In most instances, the measurements can be carried out with relative ease, but interpretation may prove difficult in the absence of relevant expertise.

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