A modified potential probe for induction charging risk assessment

Lars Fast \(^1\) and Jaakko Paasi \(^2\)

\(^1\) SP Technical Research Institute of Sweden, Electronics, P.O. Box 857, SE-50115 Borås, Sweden

\(^2\) VTT Technical Research Centre of Finland, P.O. Box 1300, FI-33101 Tampere, Finland

E-mail: lars.fast@sp.se

Abstract. Practical assessment of risks for Electrostatic Discharge (ESD) failures of semiconductor devices, due to charges induced on devices in a manufacturing or repair environment of electronics has been difficult, because easily measurable parameters such as the electrostatic field and the potential of a charged surface do not directly quantify the risk. In this paper a new method of assessing the risks with induction charging of a sensitive device is presented by introducing a well-defined dummy device, which is a simple modification of the probe of DC type non-contacting electrostatic voltmeter. By placing the modified potential probe (mimicking large sensitive device) in front of charged surface, risks of ESD failure for a device due to induction charging can be assessed. The electrostatic response of the probe at different distances between charged surface and the probe has been verified by numerical model calculations.

1. Introduction

Charges induced on Electrostatic Discharge (ESD) sensitive devices should be limited in order to protect them from ESD failures when they are exposed to electrostatic fields. Manufacturing and repair of electronics is done inside an ESD Protected Area (EPA), where electrostatic fields are mainly low, but could be of considerable level near some equipment including process essential insulators. Safe handling of ESD sensitive devices (ESDS) near such equipment requires that risks of ESD damage due to charge induced on devices are assessed and managed.

In international standards for the protection of electronic devices from electrostatic phenomena there are recommendations that ESDS should not be exposed to electrostatic fields exceeding 10 kV/m (IEC 61340 Parts 5-1 and 5-2) \([1]\) and if the potential exceeds 2000 V the distance from ESDS to the charged object should be more than 12 inches (ANSI/ESD S20.20) \([2]\). In neither of these standards one tries to measure the charge induced on a physical device or to connect thresholds for device failure to the measured ESD susceptibility of devices given in data sheets. A reason is that it is difficult to connect these limits of the electrostatic field with the amount of induced charge on a device, since this depends on the geometry of the device and the geometry of the electrostatic problem. Therefore, practical assessment of risks for ESD failures of devices in a manufacturing or repair environment is very difficult.
In this paper we present a new method of assessing the risks with induction charging of a sensitive
device by introducing a well-defined dummy device, which is a simple modification of the probe of
DC type non-contacting electrostatic voltmeter. Experiments showing the function of the modified
potential probe are compared with model calculations of the induced charges in order to verify the
response of the modified potential probe.

2. Description of the modified probe
The probe for the measurement of charge induced on a sensitive device is a system consisting of a
fixed metal coin, a fixed capacitor and the standard probe of any DC type of non-contacting
electrostatic voltmeter. Henceforth we call the coin-capacitor-potential probe system as a modified
probe.

The modified potential probe is simple: a small circular copper coin with the diameter 15 mm is
placed 3 mm from the opening of the potential probe, and then a grounded 2 pF, low leakage current,
capacitor is connected to the copper coin. The copper coin is held in place by a 2 cm long, Nalgene,
plastic cylinder. This modification implies that we are averaging the potential with the aid of the coin
and also mimicking a specific size of the sensitive component and grounding it through the capacitor.
The measured potential of the copper coin is directly proportional to the induced charge on the coin.

When we measure the potential of the coin we also indirectly measure the induced charge on this
dummy device. In Figure 1 we can see a schematic picture of the experimental set-up as well as the
modified field probe, but without the Nalgene cylinder. The ground plane is indicated to be present
essentially everywhere in figure 1. It is important to make the measurements close to a specified
surface to be able to compare the experimental results with the model calculations.

---

2 pF Capacitor

Probe

Instrument

Coin

1000V

Ground

Figure 1 Schematic picture of the experimental setup, the charged plate is marked 1000V. The dotted
lines are the schematic connections between objects.

3. Model and experimental results
The electrostatic response of the modified probe at different distances between the charged surface and
the probe was verified by numerical model calculations. To model the system described above and in
figure 1, we assumed that the charged plate (charged to 1000V) was shaped as a coin (with the radius
0.13 m) and that the charge density on this plate was constant. The charged plate was kept parallel and
at a distance of 5 cm from a large ground plane. The dummy device, i.e. the coin with the radius 7.5
mm, was kept at a variable distance from the ground plane. In the calculations the dummy device is
grounded, during the experiment it is grounded through a capacitor of 2 pF. The coin of the dummy
device coin was assumed to have a constant charge density and zero thickness in the calculation. All
coins were centred at the same point and assumed to be parallel. The grounded metal plane was, during the calculation, assumed to be infinite and it was used as a mirror plane. The exact value of the potential was calculated along the z-axis, that is, along a perpendicular line going through the centres of the coins.

We are presenting two different models, referred to as Model 1 and Model 2, where Model 1 assumes one constant charge density on the metal plate and Model 2 assuming two different but constant and concentric charge densities on the metal plate. Neither of these assumptions are correct, but they are sufficiently good to capture the essence of the measurement. Model 1 is given by Equation 1:

\[
V(z) = \frac{\sigma}{2 \varepsilon_0} \left[ \left( (z-d)^2 + R^2 \right)^{\frac{1}{2}} - |z-d| - \sqrt{\left( z + d \right)^2 + R^2 + z + d} \right] - \frac{\sigma_i}{2 \varepsilon_0} \left[ \left( (z-d_i)^2 + R_i^2 \right)^{\frac{1}{2}} - |z-d_i| - \sqrt{\left( z + d_i \right)^2 + R_i^2 + z + d_i} \right]
\]  

(1)

In Equation (1) the relation between the potential \( V \) along the z-axis and the charge densities \( \sigma \), the radius of the coins \( R \) and the distance between the coins and the ground plane \( d \) is given \( z = 0 \) implies the location of the ground plane), the parameters labelled with an index \( i \) are the induced charge parameters (the dummy device coin). The equation containing two coins, together with the boundary condition of 1000 V (with no dummy device present) on the first coin and 0 V on the dummy device coin adds up to the desired equation plus boundary conditions. The charge density of the dummy device is calculated from these facts. This is the induced charged density, i.e., the induced total charge. Part of this calculation can be found in standard textbooks [3, 4].

For Model (2) essentially the same equation is used, however the charge density on the charged coin is split into two densities and an additional radius is introduced.

We present the experimentally measured potentials and the calculated potentials as function of the distance from the ground plane. We can see a good agreement between the induced potentials on the dummy device between the experiments and the calculations for large distances. However, when the dummy device, is close to the charged plate the experimental data doesn’t agree
with the Model 1 calculation. The reason for the discrepancy is that the model is over simplified at small distances between the dummy device and the charge coin. The assumption of a constant charge density on the first coin is no longer valid; the solution is to work with two constant concentric charge densities instead of one and two different radiiuses of the coin, one physical and one effective. With the Model 2 calculation we can account also for small distances between the charged plate and the dummy device as indicated in figure 2.

4. Use of the modified probe for induction charging risk assessment

When placed in an electrostatic field, the measured potential of the modified probe is directly proportional to the charge induced on the coin. Both the potential as well as charge induced on the modified probe can be used for the assessment of risks for ESD failures.

In addition to this information we also need a scaling factor for the ratio between the potential without the dummy device and the measured potential of the 2pF capacitor for estimating the energy transfer. This scaling factor can be obtained from a simple capacitive division. It is around 5.

We illustrate that by examples. Assume that we have a discharge energy susceptible device having Machine Model (MM) [1,2] withstand of 50 V. That corresponds to discharge energy of 250 nJ (= 0.5·200 pF·(50 V)²). To induce the same amount of energy in the dummy device of the modified probe, we would have to measure 224 V on the modified probe (2 pF capacitor), using the scaling relation. If on the other hand the device is voltage susceptible, the key parameter to monitor is charge induced on the dummy device. A charge threshold for the field induced failure can be calculated from the standard Charged Device Model (CDM) [1] test data of the device by multiplying the CDM withstand voltage by an appropriate device capacitance [5,6]. Assume that a real device has a charge threshold of 1 nC. The same amount of charge is induced on the 2 pF dummy device at the modified probe potential of 500 V.

The concept of the modified probe can be extended to simulate charge induced on a Printed Wiring Board by increasing the diameter of the coin and the value of the capacitor through which the coin is grounded.

5. Conclusion

The model calculation together with the confirming experiments shows that one can measure the induced charge on a dummy device with a potential probe at any distance, not only close to the surface of the source charge. Most DC potential probes on the market are constructed to accurately measure the potential at a distance of 2-6 mm from the source charge and with a minimum capacitance to the object of around 2 pF. In the experiments we used a modified probe of 15 mm in diameter, but the size could be varied to mimic other device dimensions.

The modified field probe does not only provide information about the induced charge at any distance from the source charge, it also provides information of an effective potential in the point, i.e. the potential a grounded device is exposed to in the electric source field. Both the effective potential and the induced charge can be used for risk assessments, depending on what is an appropriate parameter to control.

References

[1] IEC technical reports 61340-5-1 Ed 1.0 1998, IEC 61340-5-2 Ed 1.0 1999
[2] ESD Association standard ANSI / ESD S20.20 1999, ESD TR20.20 Handbook 1999
[3] Jackson J D 1999 Classical Electrodynamics, third edition, (Wiley)
[4] Alonso M, Finn E J 1983 Fundamental University Physics, Volume II, second edition, (Addison-Wesley)
[5] Standard SEMI E78-1102 2002
[6] Paasi J, Salmela H, Smallwood J 2004 Electrostatic field limits and charge threshold for field induced damage to voltage susceptible device, Proc. EOS/ESD Symp. EOS-26 229-237