An Analysis of the Fields on the Horizontal Coupling Plane in ESD testing

Stephan Frei
Technical University Berlin, Einsteinufer 11, 10597 Berlin, Germany
ph.: ++493031479148, fax.: ++493031421142
frei@ihs.ee.tu-berlin.de

David Pommerenke
Hewlett Packard, 8000 Foothills Blvd, Roseville, CA 95747, Mailstop 5603
ph.: 916 785 4550, fax: 916 785 3082
david_pommerenke@hp.com

Abstract: Field levels in indirect ESD test setups are not known yet. It has been proposed to ANSI and IEC to use a horizontal simulator position instead of a vertical position in indirect ESD testing. The paper shows the field values on the Horizontal Coupling Plane for different topologies in comparison to human ESD and questions if the goal of the change - a reduction of the simulator influence - will be achieved. Also investigations dealing with the sensitivity of digital devices to impulsive fields are presented.

Introduction

Without specifying field values ESD-Standards (ANSI C63.16-IEC 1000-4-2) [1,2] require to test the sensivity of EUTs to the fields of ESD. They try to define the fields by the short circuit current and some geometry information. This specification leaves too many parameters undefined [3]. Field failure due to indirect ESD have been reported.

Two geometries are used in indirect ESD testing: ESD to a 1.6 x 0.8 m HCP (Horizontal Coupling Plane) or discharges to a second metal plane, the VCP, (Vertical Coupling Plane) located 0.1 m from the EUT which is located in the middle of the HCP.

Simulators are designed to fulfill the current specification. To our knowledge manufacturers normally do not pay attention to the radiation properties which are mainly influenced by the housing, the inner construction and the ground strap. Fields of simulators from different manufacturers may vary significantly. Even the position of the handle may influence the fields [3].

Presently the simulator is positioned at a distance of 10 cm to the EUT, perpendicular to the HCP. A new horizontal simulator position with discharges to the edge of the HCP was proposed. One argument for the new position is a possible reduction of the difference in test results between different brand simulators.

Although calibrated field measurements in different geometries have been done by [3,4,6,7,4,5,6] we are only aware of one publication on fields in a geometry which is somewhat similar to a HCP.

Iwata et.al. [5] measured qualitatively the electric field above a 0.5 m x 0.5 m metallic plate excited by discharges to its edge by

As they did not use a calibrated sensor no field values are given. But their data indicates stronger fields for a vertical simulator compared to a horizontal simulator position.

The first and main section of this paper presents an analysis of the field on the HCP for different brand simulators, different grounding methods and discharge positions.

Besides the simulator position and its geometry the ground strap routing influences test results. The second session shows this influence on an actual EUT. The third section presents information on one bit error causing mechanism in digital EUTs during ESD testing.

1 Fields on the HCP

The measurements were done on an ESD setup, Fig. 1 and Fig. 2. The ANSI setup differs only in the grounding scheme: Instead of two 470 kΩ ANSI uses two 1 MΩ and one 2 kΩ resistors for the grounding of the HCP to ground reference plane (GRP). All measurements were done at positive 3 kV using a IEC-1000-4-2 simulator in contact mode. Due to the linearity of a simulator in contact mode, the fields for other voltages are easy to calculate. The broadband E- and H-field sensors [3] were calibrated. They offer a bandwidth of 1.8 Ghz for the H-field and 2 Ghz for the E-field. Their output was feed into a Tektronix

7104 scope (BW: 1GHz). Waveforms were captured by a camera system.

Most measurements were done using a 700 MHz optical link to avoid influences on the grounding of the HCP by sensor cables.

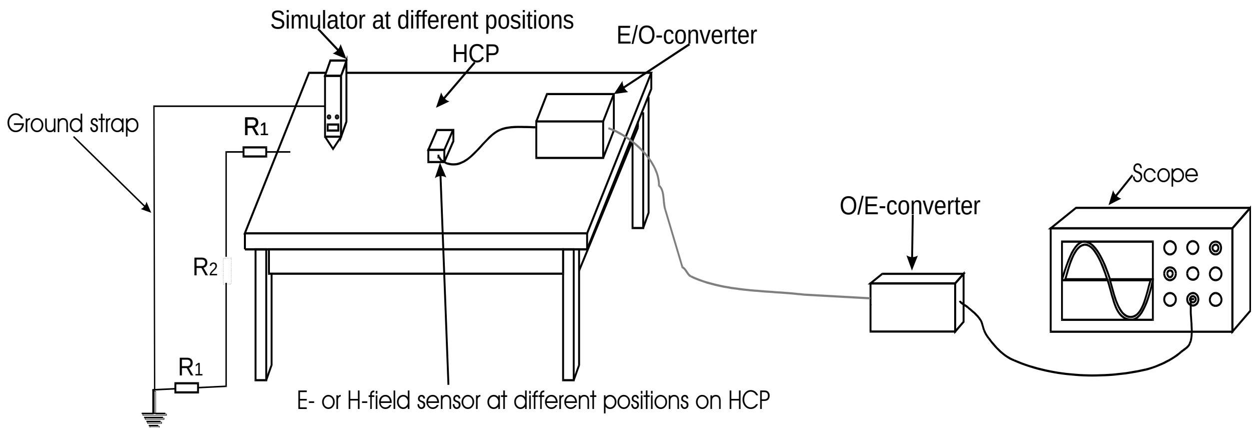

Fig. 1: Field measurement setup, discharges on the HCP (Resistors: ANSI: R1=1 MΩ, R2=2 kΩ; IEC: R1=470 kΩ, R2=0 Ω)

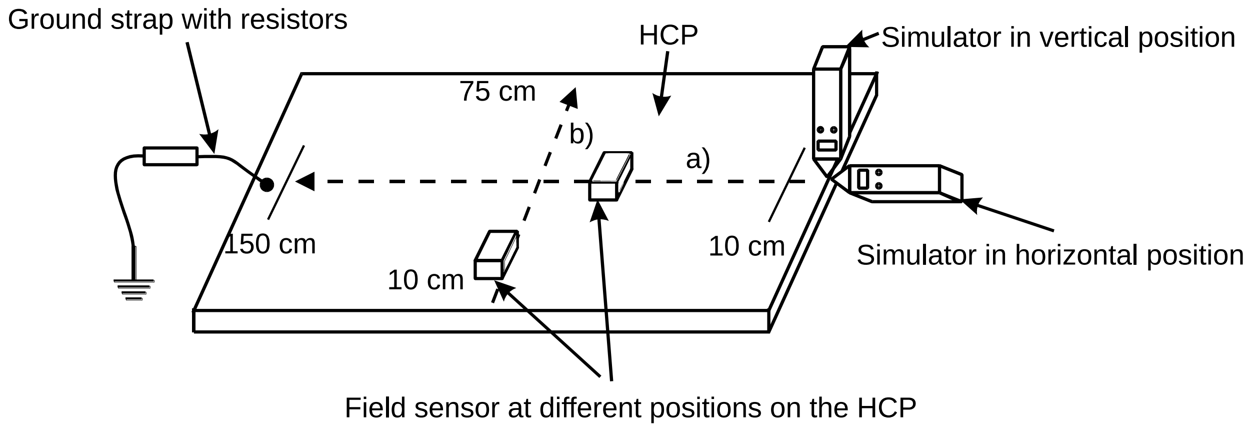

Fig. 2: HCP field measurement setup, discharges to the edge of the HCP

1.1 Fields on the HCP caused by ESD to it

Discharges to the HCP are intended to simulate real world ESD nearby to the EUT. To do so, the simulator is discharged to the HCP at a distance of 0.1 m from the EUT. Only for large EUTs the discharges are applied to the edge of the HCP.

In the proposed new indirect test method the simulator is held horizontal and discharges are applied to the edge of the HCP. One argument for the change is a possible reduction of the brand to brand variation of test results.

As shown in Fig. 2, measurements were taken for different sensor positions on the HCP to determine the field distribution. Fig. 3 and Fig. 4. plot the field peak values vs. distance to the simulator.

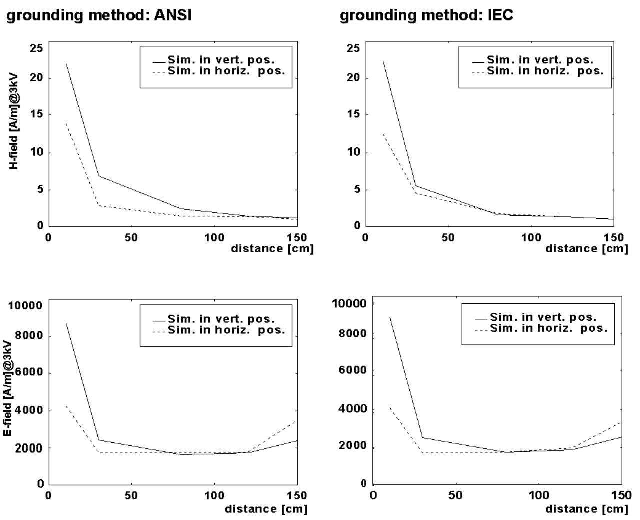

Fig. 3: Amplitude of fields on the HCP vs. distance to simulator (Fig. 2, path a)), Simulator a)

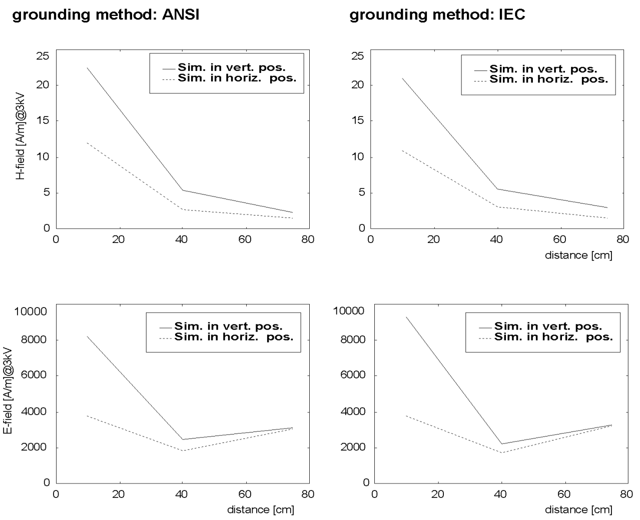

Fig. 4: Amplitude of fields on the HCP vs. distance to simulator (Fig. 2, path b)), Simulator a)

The H-fields decreases with increasing distance roughly by 1/r. They are determined by the current density on the HCP which would be expected to decrease by 1/r on an infinite plane.

The behavior of the E-field is quite different. Initially the amplitude decreases. But as the edge is approached the fields increase again. The effect is stronger for the horizontal simulator position. This can be explained by the superposition of the original wave with a wave reflected by the edge. If the simulator is held horizontally an equally strong wave at the bottom side of the HCP is launched. At the edge this wave may partially reach the upper side and add to other field components.

If the simulator is discharged in the middle of the HCP and the fields round the simulator were measured, a similar behavior of the fields vs. distance can be observed.

The location of the ground strap has nearly no influence. Its impedance is to high to show an influence in the nanosecond time scale.

1.2 Comparison of fields from different brand simulators on the HCP

To analyze if a horizontal simulator position reduces the influence caused by different brand simulators, three commercial simulators were compared. Verified by measurement all fulfilled the IEC-1000-4-2 current criteria.

The three simulators were discharged at the edge of the HCP as shown in Fig. 2. Some selected results are shown in Fig. 5.

If the simulator is discharged in vertical position the fields are stronger compared to discharges in a horizontal position. In close proximity to the discharge point, the fields of the different simulators used in a vertical position vary very strongly.

The H-field peak value of simulator c) is 50 % less than that of simulator b). For E-fields the differences are even more drastic. The amplitude of the smallest pulse is 65% down from the strongest pulse. The field impedances are around 377 Ohm.

For the horizontal simulator position the field changes in two respects:

- The field amplitudes are reduced by a factor of approximately 2. This agrees to results of Fig. 3 and Fig. 4. Iwatas [5] measurements also showed a reduction of the voltage induced in a dipole by a factor of 3.
- The brand to brand differences seen for the simulators used in this investigation decrease: A difference of 28% remains for the H-field and only 5% for the E-field.

The measurement indicate that reproducibility could be enhanced using a horizontal discharge position. The change can be explained as follows:

a) The simulator - sensor distance is larger in a horizontal position.

b) Most of the currents in the simulator flow parallel to its tip, i.e. they cause near fields in the direction of the tip, but they do not radiate in this direction. At a simulator - sensor separation of 0.2 m there are far field conditions for the initial rise. If the simulator is held parallel to the HCP the sensor will mainly pick up the fields caused by the expanding discharge current in the HCP. As this current is better defined than the current distribution on the simulator a reduced brand-to-brand influence is seen.

If the sensor would not be placed on the HCP but above it, radiation from the simulators would again be important, i.e. the effect of reduced brand-to-brand variation may vanish or be reduced for taller EUTs.

There are more reasons to caution: Simulators were chosen arbitrarily. Other brand simulators may react different.

To really overcome the uncertainty, a field specification is needed. Such a field specification should call for transient fields which match human hand-metal ESD. But air discharge risetime depends not only on voltage but mainly on arc length. For that reason the comparison needs to define both parameters for the air discharge. If a risetime of 0.7 ns to 1 ns is accepted for contact mode simulators the current risetime of human ESD should be the same for the field comparison. Measurement showed the following values:

Fields of an human ESD into a 3 m x 3 m ground plane. Discharging at 5 kV through a 6 mm diameter and 63 mm length metal part. Data is for arc lengths of approx. 0.8 mm which causes a risetme of approx. 0.8 ns.		
Distance m	Peak E-Field kV/m	Peak H-Field A/m
0.1	12.0	26.5
0.2	4.5	8.1
0.3	3.0	5
0.5	1.4	3.0
0.7	0.95	2.1
0.9	0.6	1.3
1.2	0.4	1.1

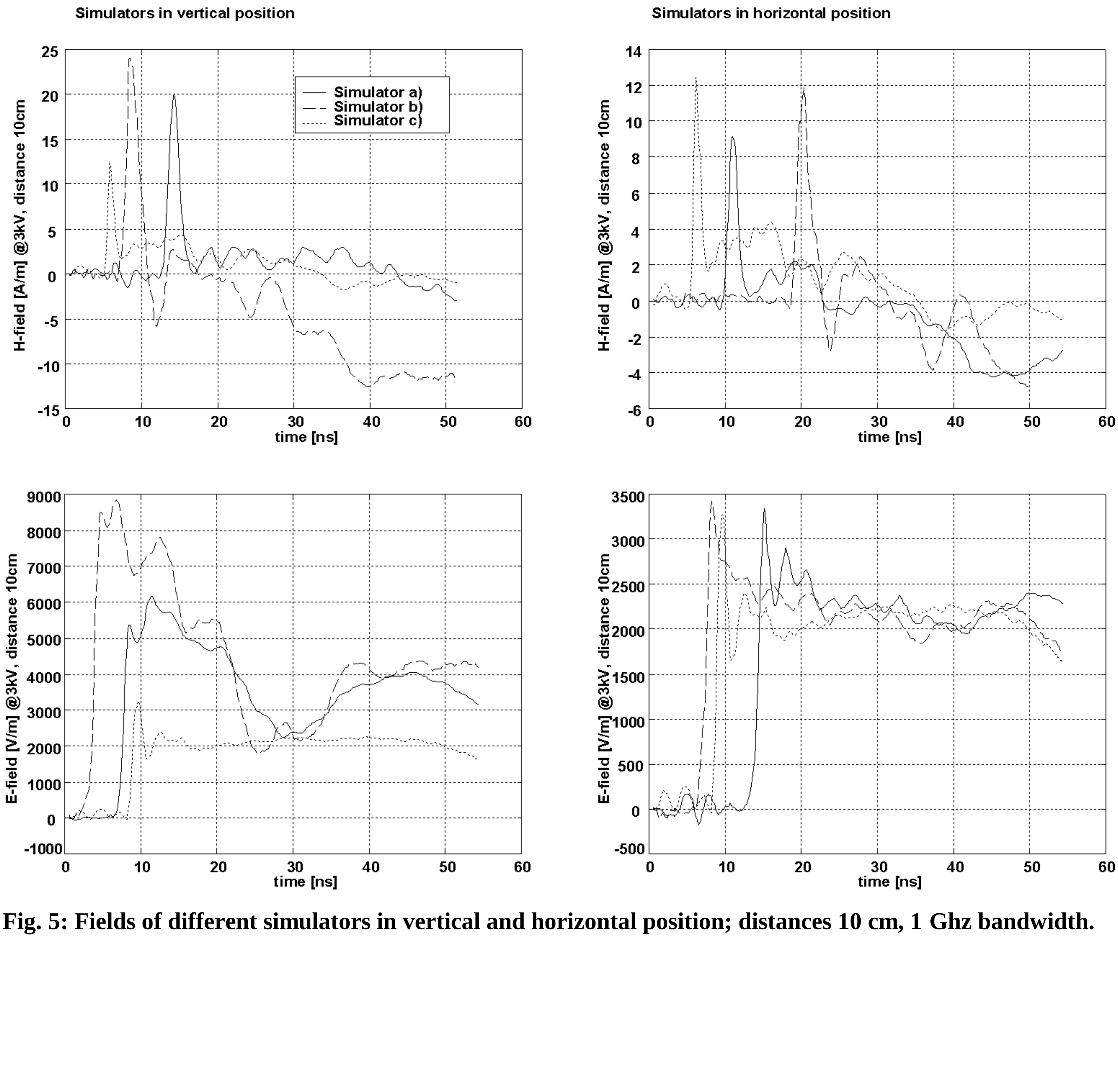

Fig. 5: Fields of different simulators in vertical and horizontal position; distances 10 cm, 1 Ghz bandwidth.

Some other considerations may be in favor of a vertical generator:

- The larger field strength reproduce the field strengths of a nearby ESD of a human better.
- If a distance of 0.1 m to the EUT shall be remained, the EUT has to be moved around on the table to test all sides of the EUT. This movement will be detrimental to reproducibility due to EUT cable routing.

1.3 Fields on the HCP caused by discharges into the VCP

Besides HCP discharges the standard requires discharges into a 0.5 m x 0.5 m VCP. Again, the coupling into the EUT is caused by fields. Grounding of the VCP and HCP are alike. The ground straps of the HCP and the VCP are connected to the GRP. There is no direct connection between VCP and HCP. Fig. 6 shows the setup used. The VCP was located on a fixed place on the HCP. E- and H-field sensors were moved on the HCP. The results of the measurements are shown in Fig. 7:

- The peak magnetic field decreases monotonously with distance.
- Again there is hardly any difference between grounding as required by ANSI or by IEC.
- The amplitudes are smaller compared to the amplitudes shown in Fig. 3. At 0.1 m the E-Field value is close to the E-field value at 0.1 m on the HCP for a horizontal simulator position. But the magnetic field is much lower. This is caused by the enlarged distance between the simulator and the sensor and probably a reduced discharge current. The current is reduced by the small size of the VCP and its high impedance grounding.
- The electric fields show amplitudes similar to those of direct ESDs to the HCP. For small distances the fields decreases monotonously. But at approx. 0.55 m the negative peak value becomes larger than the positive peak value. This is caused by superposition of the different waves which travel on the VCP and the HCP.

In Fig. 8 the impedance of the fields generated by the VCP is shown. Here it is defined as the peak E-Field divided by the peak H-field even if they do not occur at the same time. The field impedance is very high at the standardized test distance of 0.1 m. Failures due to the VCP are rare and mainly seen in high impedance circuits. Again the grounding methods do not influence the fields for the first couple 10 ns.

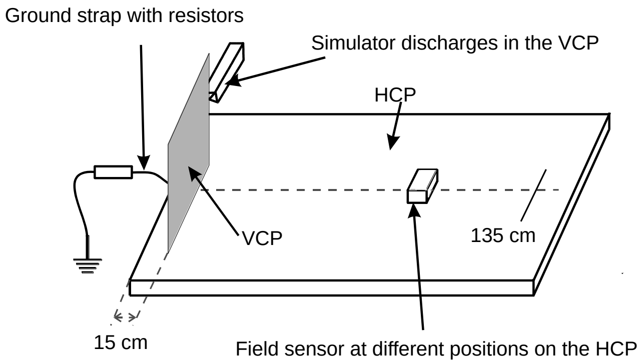

Fig. 6: Setup for measurements with the VCP

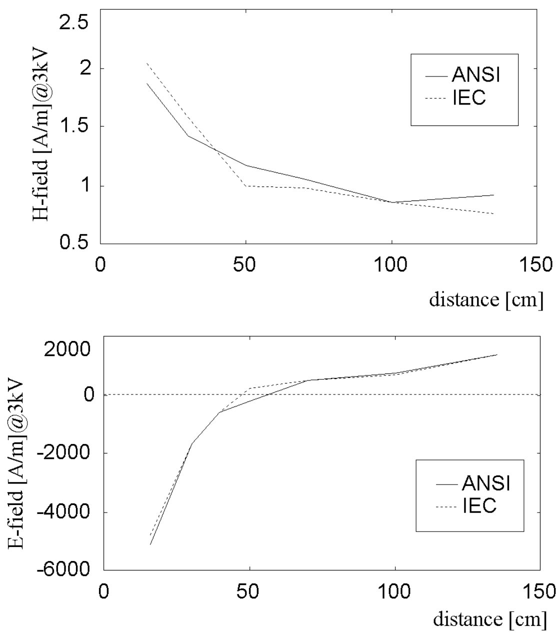

Fig. 7: Amplitude of fields on the HCP vs. distance to VCP

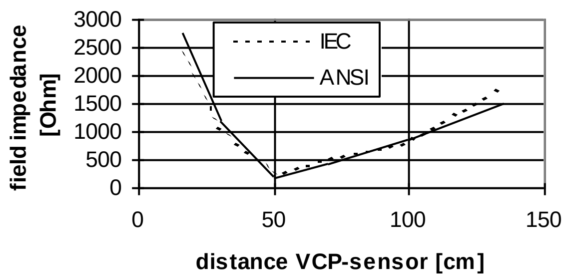

Fig. 8: Impedance of the fields caused by discharges to the HCP

2 Influence of the ground strap

An other undefined parameter in ESD-testing is the influence of the ground strap. Measurements of the

fields underneath it and at a distance from it can be found in [3].
Here the influence of the ground strap to a real EUT is described. As EUT a data acquisition board with a 16-bit microcontroller was used. The size of the board was 160 x 100 mm. The ground strap was traced in different manners as shown in Fig. 9.
For real digital EUTs the sensitivity is a function of time. It depends on the inner state of a digital system (they change e.g. with the program). Statistical methods are needed to calculate the uncertainty of a test result.
To test the influence of the ground strap the position of the ground strap and the voltage were varied. The voltage of a contact mode ESD-simulator was increased in steps of 500 V, from 500 V to 10000 V. The position of the ground strap was changed from -110° to +110° in 22.5° steps as shown in Fig. 9. For each voltage and each position of the ground strap 200 pulses were applied. To calculate the failure probability the EUT function was verified after each pulse. Fig. 10 shows the results. To read it correctly look at the white rectangular. It indicates a measurement with 5 kV at a ground strap angle of +45° (setup in Fig. 9). The failure probability given by the shade in Fig. 10 is between 0.5 and 0.75.
The influence of the ground strap is easy to see. The borderline of a failure probability of more than 0.75 is shifted under the ground strap by approximately 2500 V. If the ground strap is traced close to the EUT a test becomes more severe.

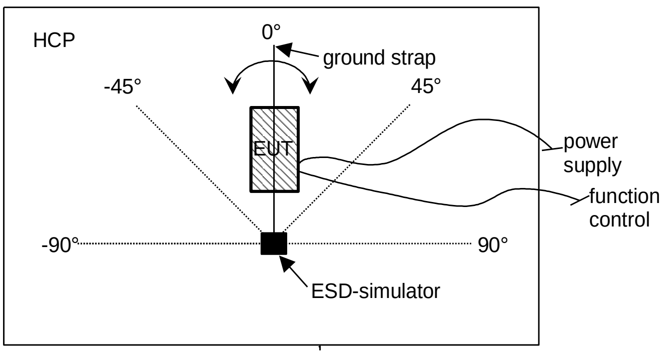

Fig. 9: Setup to investigate in the influence of the ground strap (distance simulator-EUT 10 cm)

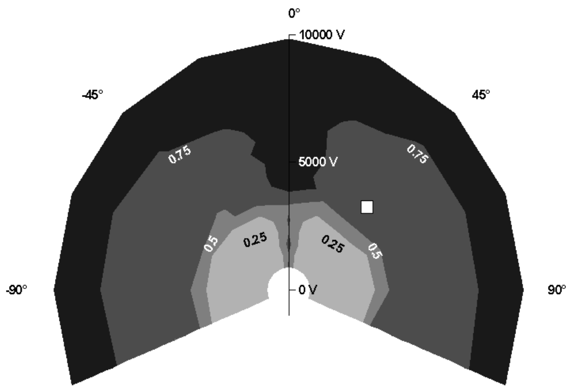

Fig. 10: Failure probability of a microcontroller board vs. the position of the ground strap and the charging voltage of the ESD simulator. Voltage is indicated by the distance from the origin. Different shades are used to plot failure probabilities.

3 Sensitivity of electronic devices

How do the fields affect digital systems? Many different methods to define a severity of ESD fields have been proposed: WARP, Epeak/risetime, Peak field values, etc.
The answer to this is somehow EUT dependent. Nevertheless, studies using well defined variation of one parameter provide some inside and allow to test to what extend simple coupling models and signal integrity methods like dynamic threshold data can be applied.

Susceptibility Of Logic Devices

The circuit used was very simple but nearly all digital circuits are based on similar circuits. The results presented were gained with CMOS logic devices. Results with TTL logic are not presented but they were similar.
A simple PCB was designed to do parameter studies. The main part of the experimental setup consists of two integrated circuits and a loop.
Integrated circuits of the SN74XX family were used. Between an inverter (SN74XX04) and the clock input of a flip-flop (SN74XX74) a small loop is mounted. This loop simulate a bad PCB layout. The area of the loop is 6 cm x 6 cm. The rather large size was dictated by the field strengths and risetimes available in the TEM cell.

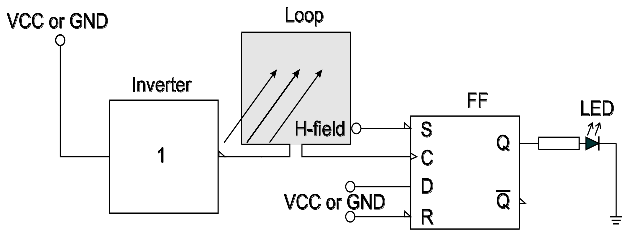

Fig. 11: Schematic of a simple model circuit

A circuit diagram is shown in Fig. 11. The circuit was located in an open TEM cell. Varying trapezoidal pulses were applied by a AVTECH AVL-2-C-T pulse generator. The rise time and the amplitude of the pulse were varied. The pulse width was held constant (40 ns), changes of the pulse width did not influence the results.

It was assumed that the dimensions are small compared to the shortest wavelength. Provided that the input impedance of the flip-flop is large, the induced voltage can be calculated (the loop inductance is neglected) using the formula:

$$U_{ind} = -\mu_0 \oiint_{A_{loop}} \frac{dH}{dt} dA \qquad (1)$$

in a homogeneous field this simplifies to:

$$U_{ind} = -\mu_0 A_{loop} \frac{dH}{dt} \qquad (2)$$

Using impulsive fields with trapezoidal pulses the derivative of the pulse is constant during the rising edge and can easily be calculated by:

$$\frac{dH}{dt} = \frac{H_{\max}}{t_r} \qquad (3)$$

Formula 2 can so be simplified to

$$U_{ind} = -\mu_0 A_{loop} \frac{H_{\max}}{t_r} \qquad (4)$$

Which is valid for the rising edge of the trapezoid. Dynamic threshold data shows that not only the amplitude of the induced voltage determines the failure behavior also the time a voltage is applied to a circuit is important. The energy of the voltage pulse must be larger than a certain threshold. Conditions as used in dynamic threshold measurement can be achieved by the trapezoidal field pulses as they induce a constant voltage in the loop during the rising edge.

Fig. 12 shows a dynamic threshold diagram. A varying voltage pulse was applied to an input to record the threshold level.

In Fig. 13. the risetime and the amplitude of the field pulse were varied. The EUT shown in Fig. 11 was used and the behavior of the flip-flop was observed. Using formula (4) the induced voltage was calculated and plotted left on Fig. 13. It is very close to the dynamic threshold data. This indicates that dynamic threshold data and simple induction models can be used in indirect ESD failure prediction. An example would be the influence of aperture coupled fields for a reduced aperture size.

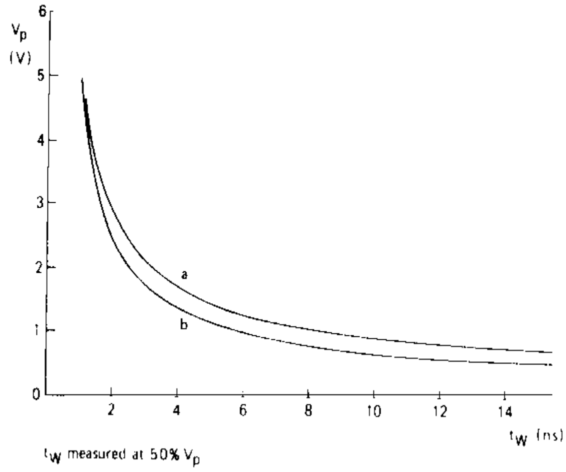

Fig. 12: Maximal amplitude of a pulse without state change. Amplitude versus pulse width; a: HC-logic, b: HCT-logic (Source: Valvo: CMOS-Databook)

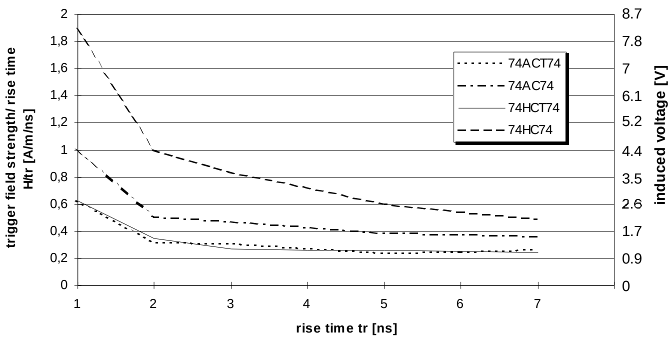

Fig. 13: Measured thresholds of a flip-flop

4 Conclusions

Measurements of fields on the HCP were done with calibrated equipment. The data provide absolute field values. They indicate a better reproducibility of indirect testing but at reduced test level for a horizontal simulator position compared to the present vertical simulator position.

Data for VCP discharges point at very high field impedances at the 0.1 m test level.

5 Acknowledgment

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6 References

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