

# Charged cable event

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## 1 Goal of the ongoing investigation

- Understand threat (Occurrence rate, severity, energy source, and discharge mode).
- Understand counter methods.
- Define test method.
- Define test levels.

## 2 Energy sources for the CDE

Charges do not simply appear.

Moving air does not cause significant tribocharging.

Trapped charges within the polymer from production are most likely not significant.

Voltages can appear between:

- All twisted pairs and ground (common mode).
- Between wires of a single twisted pair (differential mode).
- Between different pairs (mixed mode).

For that reason, care must be taken in setting up experiments, reporting them and in analyzing real world voltages. Note that discharge processes can turn one voltage into another.

Different sources can provide the energy needed for the CDE. They are either of electrodynamical or electrostatic nature. Especially in tribocharging it is often not easy to understand how charge carriers are separated and how they effect charge carriers in close by conducting structures.

- **Tribocharging (surface charges)**

**Example 1:** A cable is dragged along the floor. Tribocharges are created at the surface of the cable.



**Figure 1** *Tribocharging example 1. For simplicity, only one twisted pair is shown.*

The positive tribo-charges on the surface of the cable attract negative charges on the twisted pair. This causes a charge separation leading to positive charges at the ends of the cable. Note that there is NO net charge on the twisted pair. Still, if the cable is plugged into a directly or capacitively grounded connector there will be arcing. This arcing will charge the twisted pair!

- **Tribocharging (space charges)**

**Example 2:** Lets assume a LAN cable has a large voltage between its twisted pairs and the surrounding. This voltage will cause charge carriers to migrate into the dielectric. Now the twisted pairs are grounded for a few seconds. During this time, all charge carriers will be neutralized which can move quickly, i.e. those on the copper wires. But the charge carriers inside the insulation (space charges) will not be removed. Thus after removing the ground connection, the space charges will cause charge separation on the wires leading to a potential difference between ground and the end of the twisted pairs.

- **Example 3:** A cable is placed in a strong electrostatic field and left there for some time. While it is sitting there, it will accumulate charge carriers on its surface. This carriers will polarize the wires. This will cause some of the charge carriers to migrate inside the insulation. After the cable is removed from the external electrostatic field, the charge carriers stay where they are. But those charge carriers, which had "partners" due to the external field will loose their partners. This will increase their effect on the wires inside the cable, thus increasing the voltage at the end of the cable.

- **Induces voltages**

If a cable is subjected by the field of a strong pulse (e.g., a lightning stroke, strong switching transitions on a cable close by, ESD close to the cable) a momentary voltage will be introduced along the cable. This is not a problem, as long as the cable is not connected to any network equipment. But if it is connected the voltage may [effect](#) the network equipment.

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### 3 CDE modes

Many discharge modes are thinkable. However, how likely each one of them is, remains to be seen. LAN cables can be charged in common mode and, although with a smaller likelihood, in differential mode. When a charged cable is plugged into network equipment one of the PINs will spark over first. Now a wave will travel along the cable (between cable and ground) and waves will travel between the wires. Those waves will subject network equipment on the near end (where the connector was plugged) and on the far end to high voltage pulses.

The stress the LAN receiver / transmitter will see depends on many parameter, some are:

- Is the EUT powered up or not (latch-up is only possible on powered ICs),
- Common mode or differential mode voltages,
- Near or Far end excitation,

- Impedance of the LAN cable to ground,
- Length of the LAN cable,
- Charging voltage,
- Grounding of the network equipment,
- Breakdown voltage of the isolation transformer on the LAN ports,
- Breakdown voltage of other components,
- Some parameters associated with the air breakdown physics.
- etc.

To complicate the picture, there are further situations which may cause a large overvoltage, but which do not require to plug a charged cable into the network equipment.

Some examples are (note that they are not sorted by any perceived likelihood)

#### **Case A**

A cable charged in common mode is plugged into a LAN connector. Some PINs will contact earlier than others. The moment the first PIN is connected (directly or via a spark) a current starts to flow into the LAN connector. The amount of current depends of the source impedance (common mode impedance of the cable) and the capacitance + termination impedance to ground of the LAN input. If the current flows through the isolation transformer, it will cause a differential voltage on the PHI-chip.

#### **Case B**

As case A, but it is assumed that the isolation transformer breaks down, causing a direct current injection into the PHI-chip.

#### **Case C**

As case A, but it is assumed that a passive component breaks down. This may increase the current through the isolation transformer and the PHI-chip.

#### **Case D**

If the LAN cable is attached to the network equipment, but a CDE event takes place at the far end of the cable (e.g., by plugging a cable into a charged, non-grounded system) a pulse will travel along the cable. First it is assumed that the pulse is in common mode large enough to trigger event A, B or C.

#### **Case E**

As case D, but is assumed that the pulse is in differential mode (e.g., due to PIN sequencing). In this case its amplitude can be much lower to cause damage.

#### **Case F**

A strong electromagnetic pulse (e.g., a lightning stroke not too far away) induces a voltage along a cable. Due to the twisting of the pairs, there will be hardly any differential voltage, but there may be large common mode voltage. This leads to a breakdown at one or both ends of the network equipment. Once one of the wires is connected to e.g., ground a current will flow causing a differential mode signal. This is coupled via the isolation transformer into the PHI-chip.

## 4 Instrumentation of possible use for CDE investigation and test methods

### CDE simulation: ESD generator

System level ESD generators (in contrast to device level simulators) are most often built to the specifications given in IEC 61000-4-2. They provide voltages up to 30 kV. The pulse form looks somewhat like a double exponential pulse (well, somewhat).

It is defined into a short circuit (large metallic plate) by its risetime: 0.7-1ns, Amplitude 3.75 A/kV and some further parameters. This type of instrumentation is widely available. Repeatability of test results may be rather bad, as it is not easy to inject the pulse into a cable and the pulse, which will get injected, will depend on the brand of simulator used. Cost: 5000-10 000

### CDE simulation: Transmission line pulser (TLP)

In a transmission line pulse, a cable is charged to a predefined voltage (usually a 50 Ohm coax). Then the cable is connected to the output connector of the pulser using a fast switch. Most often relays are used. Relays specially designed for this purpose provide repeatable risetimes of less than 100 ps. The pulse form is a square wave (possible: oscillating square wave). Voltages of most TLPs are less than 4000 V, due to limitations in the switches. A TLP is a very good tool for this type of investigation, as its pulse probably has quite a bit of similarity with the current pulses seen on network cables (my guess, as I have not measured those pulses). Cost: 5000 – 50 000

### Occurrence rate / severity study: Electrostatic voltmeters

Electrostatic voltmeters allow to measure the voltage on a metallic surface (note that it does not make too much sense to use voltage if the surface looked at is not conducting, as the surface potential will not be equal across the surface) without touching them. In contrast to electrostatic field meters, the reading is in Volt, not in Volt/meter. Many electrostatic voltmeters (e.g. from TREK Inc.) use vibrating electrodes. Cost: 500 – 5 000

### Occurrence rate / severity study: ESD event recorders

There are many such devices on the market. HP has designed (together with TREK Inc.) an ESD event detector, which records voltage, humidity, temperature and transfer its data using a serial port. With some effort, this device could be adopted to a LAN application. Cost: 1 500.

### Further instrumentation from electrostatics

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## 5 Possible CDE test methods:

Method	Equipment	Pro	Contra
Charging a cable and plugging it into the device under test.	Voltage source	Reproduces some, but not all real world cases	Due to PIN sequencing and <a href="#">air discharge</a> , test results will probably be very unrepeatable.

Differential injection using a TLP	TLP	Directly tests for the critical differential voltage. Easy to implement.	Does not test for breakdown of isolation as most TLPs provide a limited voltage output.
Discharges to PINs Single or all	ESD simulator	Fits in present process Equipment widely available. Equipment cheap.	Result depends strongly on breakdown if <a href="#">air discharge</a> is used. If <a href="#">contact mode</a> is used, the injected current can be reproduced better, but the results will depend on the position of the ESD simulator with respect to ground and the brand of simulator used.
More ...			

For everyone, who are not familiar with ESD testing: ESD testing can be done *using “air discharge mode” or “contact mode”*. In air discharge mode, a spark will fly in air between the electrode of the simulator and the device under test. Due to some parameters of the air discharge physics, the current amplitude, risetime and current derivative may vary by orders of magnitude between discharges with no apparent change in the way the ESD was applied.

In contact mode, a fast switching relay (sub-nanosecond risetime) is used instead of a spark in air. In this case the current can be repeated from discharge to discharge very well.

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## 6 Effects of the discharge on the network equipment

In defining test methods it is important to understand the effects of the CDE event as the test method must include degradation or failure criteria.

An overvoltage event may cause the types of effects

1. Bit errors. They do not pose a problem and are not considered.
2. Loss of function by destroying PHI-chip. This is easy to detect.
3. Degradation of the PHI-chip. Degradation may not be easy to detect, as they may only show up in subtle parameters like receiver leakage current but they may reduce the life expectancy of the PHI-chips.

This may be:

- reduced output signals,
- increased noise,
- change in bias levels,
- increased leakage current of the receiver inputs,
- Further.

Parameter testing is required to detect those changes.

4. Latch-up. If the PHI-chip latches-up, its current consumption will be increased until the next power-cycle. This increased current may damage the chip or have other effects like increasing the temperature until certain chip parameters are out of spec. Temperature measurement and/or current measurement will show if latch-up has occurred.
5. Degradation of passive components. Examples for degradation are:
  - Dielectric breakdown in the isolation transformer leading to reduced isolation voltages and/or parameter changes,
  - Breakdown of capacitors leading to reduced capacitance and withstand voltages, possibly to shorts,
  - Degradation of termination resistors. This usually leads to an increase in their resistance values.

Detecting this degradation requires parameter testing.

To my knowledge it is not known how often the effects named above occur. Most likely, testing will emphasize on destruction of the PHI-chip and not on latent damage.

Further investigations are needed.

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## 7 Many questions, few answers

- 1) How does the pinning sequence effect the CDE for near and far end discharges?
- 2) How does UTP compare to STP (good ground / bad ground etc.)?
- 3) How large are charges / voltages / energies. Measuring voltages (charge?) on cables?
- 4) Is CDE damage more often observed on network equipment, which is plugged often or rare?
- 5) Understand the possible discharge events (with isolation breakdown, near end, far end, induction (db/dt), tribo charring, induction of charges.)
- 6) Understand different grounding strategies on CDE (no isolation, 75 Ohm, small / large capacitors, STP vs. UTP).
- 7) Define a test method: Isolation breakdown, differential signal etc.
- 8) How fast does a charge decay in common mode / differential mode ? Will asymmetric decay cause differential voltages ?
- 9) Which test methods exist?, To what extend have they been formed by quick & dirty without analyzing the event, or have they annexed the event ?
- 10) What are reasonable test levels in different modes ?
- 11) How can existing methods for overvoltage tests, e.g., IC-level ESD tests (CDM, MM, HBM, latch up) be utilized for the characterization of CDE robustness?
- 12) Which data exists on CDE current or voltage measurement?
- 13) Which methods were used to obtain the data?
- 14) How many network equipment ports have failed?

- 15) Is there any correlation between the number of failing ports and the environment they were used in?
- 16) Is there a winter – summer correlation to failed parts (typical for ESD)?

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## **8 Relevant literature**

J. Deatherage, D.Jones, "Cable Discharge event in LAN Environment", Level One Confidential Document.

J. Deatherage, D.Jones, "Multiple factors trigger discharge events in Ethernet LANs", Electronic Design, Vol.48, No.25, pp.111-112, 114, 116 (quite similar to the reference above)

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