Comparing Cable Discharge Events to IEC 61000-4-2 or ISO 10605 Discharges

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Abstract: Cable Model (CM) discharge events can cause serious ESD damages. Especially during the automotive production process, when numerous cables are connected to electronic devices. Here exists a potential risk for electronic devices. Typical cable discharges occurring in the automotive production environment are investigated and characterized. Possible charging effects of the wiring harness were identified. Discharge shapes depending on automotive wiring harness configurations were classified. Modelling of the cable parameters was done and cable discharge events were simulated. The simulation results were verified with measurements. Possible impacts on affected electronic control units were identified and a comparison between ISO/IEC electrostatic discharges and cable discharges was drawn.

I. Introduction

ISO- and IEC-HBM ESD tests are important for ensuring high electronic quality. The test limits for the ESD charging voltages increased within the last years up to 25 kV and more. At the same time shrinking dimensions and higher package density lead to more endangered electronic devices.

The demand for more functionality in automobile electronics causes a rising number of electronic components. These components are connected via the car cable harness. Hence the damage potential by ESD events increases.

Up to now Cable Model (CM) discharge events are investigated insufficiently. CM discharges became more important due to the fact, that a rising number of electronic devices in the automotive environment increases also the occurrence of CM discharges.

State of the art electronic device connectors minimize the risk of an HBM discharge to the connector pins. However CM discharges appear at least one time in an electronic device life cycle, during the final assembly of a car. For some network and consumer electronic devices CM discharge problems were described some years ago in [1] without consequences on the standard test processes.

In the automotive area system ESD robustness is mainly tested with IEC-HBM. Therefore it is necessary to compare IEC-HBM discharges with CM discharges to estimate the existing risk for automotive devices.

The initial point of any CM discharge event is a potential difference between the harness and the electronic component which is connected. In the moment of the approach a fast transient discharge current pulse occurs. This transient pulse may lead to failure and destruction in electronic components [2].

II. Charging effects in a wire harness

There are numerous sources for the charging process. The cable harness as well as the electronic components can be charged. Under normal environmental conditions the discharge times are long.

A. Charged Cable by Triboelectric Effect

A cable can be charged by triboelectric effects. Different isolation materials as well as any other surfaces which get into contact with the harness during assembly are potential friction partners to separate charges.

During the assembly process the cable rubs against the transport bag, the surfaces of the bodywork and other cables of the harness whereby charge separation may occur. A rise in potential on the conductor can result due to a migration of charges through the isolation layer.

Measurements in production sites are difficult, but under laboratory conditions (21°C, 35% RH) it was easily possible to charge an automotive wiring harness up to 200 V [2].

B. Charged Cable by Discharge

A cable can be charged by an applied discharge. This may occur by a charged worker touching the harness or a charged electronic unit which was connected before. The charge will remain in the system till a discharge path is available.

C. Charged Cable by Electrostatic Induction

Surfaces can be charged due to packaging and handling. Plastic housings can be charged on a high level if e.g. a protection film is removed. The potential can be transferred to the harness due to induction charging effects.

D. Charged Cable Discharge time

The dwell time of the charges in the wiring harness after a charging event gives an indication how long a potential risk for a CM discharge is present. An R/C like discharge occurs when a charged wiring harness is discharged through the isolation material and air. Laboratory discharge measurements for an automotive wiring harness show that a potential risk exists for a long time. This behaviour is described in Figure 1 depending on the charging voltage and humidity.

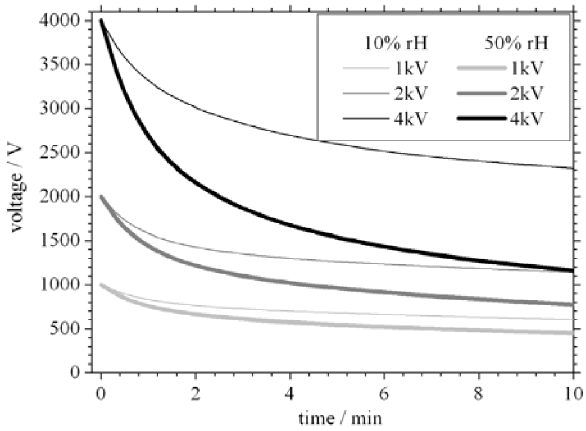

Figure 1: Discharge example of an isolated automotive wiring harness under laboratory conditions

III. Failure Models for ESD

ESD can cause numerous failure modes [3]. Therefore no typical failure model is available due to the high variance of ESD failures. For basic investigations and comparisons of the methods simple failure criterions are defined to estimate the risk potential.

A. Thermal Effects

The discharge pulse energy combined with a high peak power causes several thermal defects in electronic parts.

The well known IEC-HBM pulse can be used, to assume a reasonable energy limit for thermal effects.

The energy of IEC-HBM models is stored in the capacitance of the discharge network.

$$E_{HBM} = \frac{1}{2} C_{HBM} U^2 \tag{1}$$

It is possible to approximate the amount of energy for the tested device with the assumption, that the stored energy is dissipated in the IEC-HBM network impedance and the discharge impedance of the tested device (DUT).

With the simplified assumption that no energy is radiated and the condition

$$C_{protection} >> C_{HBM}$$

the energy ratio can be given with:

$$\frac{E_{DUT}}{E_{HBM}} = \frac{R_{DUT}}{R_{HBM} + R_{DUT}}$$
$$with (1)$$
$$E_{DUT} = \frac{R_{DUT}}{2 \cdot (R_{HBM} + R_{DUT})} \cdot C_{HBM} U^2 \tag{2}$$

The discharge energy for an 8 kV IEC-HBM discharge (330 Ohm, 150 pF) in a 50 Ohm system can be calculated with:

$$E_{\max\_8kV} = 0{,}63\ mJ \tag{3}$$

The IEC-HBM limit of 8 kV is valid for many electronic devices as a minimum limit for contacted discharge events. The energy amount of 0.63 mJ will be used in the following to characterise the CM discharge events.

B. Overvoltage

Voltages beyond the technical limit of an electronic device will degenerate structures and cause several failure modes. As a common protection method a capacitive element on an input pin is used, as shown in Figure 2. This protection method is less effective for fast transient pulses due to the high pass behaviour. Voltage spikes may pass the protection.

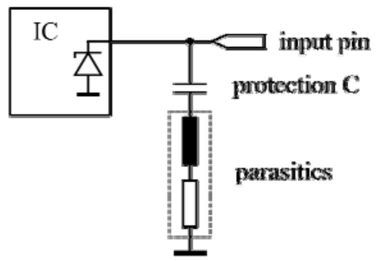

Figure 2: ESD protection capacitance with parasitic

An IC pin can withstand a certain voltage, depending on the applied IC technology. Therefore a voltage above 40 V can be given as a first preliminary voltage limit for an IC pin.

IV. Proposal for CM-Testing

A. Proposal for test-setup

Due to the high variance in an automotive wiring harness a typical configuration has to be specified. To ensure a reasonable and stable measurement environment, it was necessary to assume “standard harness conditions” and a defined discharge path. A wire of 1 m length and a impedance of 240 Ω was chosen. The charged wire was discharged into a 25 Ohm resistor protected by a 10 nF capacitor. This configuration corresponds well to an electronic control unit with a 10 nF EMI capacitor on the input pin and an active ESD protection structure on the connected IC input.

Figure 3 describes a possible measurement setup to characterise CM discharges. This configuration was used for the following CM discharge measurements. The setup was placed in a climate controlled ambient (22°C, 35% rH). The electrical contacts in point A and B are contacted with an automatic system, which approaches with the speed of 150 mm/s to the discharge point. A wire which has a defined impedance (240 Ohm) was charged with a high voltage source (HV generator) in point A. The HV generator was disconnected and the wire was discharged into a test board in point B. The discharge current was measured with a Tektronix CT6 current probe. The voltage on the discharge resistor (25 Ohm) was measured after an impedance adaptation to 50 Ohm. The discharge was recorded and the average of 250 discharge events was taken for each discharge voltage.

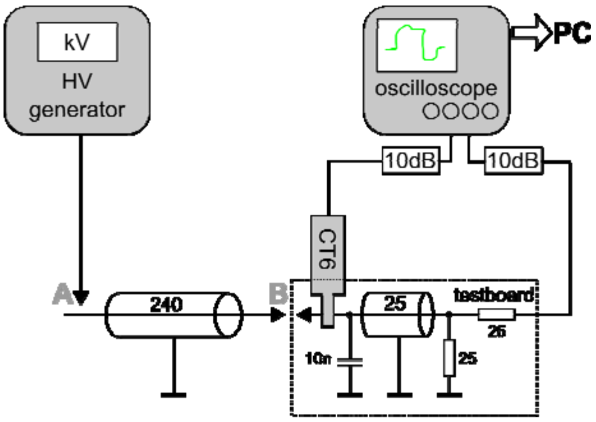

Figure 3: Possible CM discharge measurement setup

V. Separation between Cable Model (CM) and IEC-Human Body Model (HBM)

A useful criterion to distinguish between IEC-HBM and CM discharges is the rise time of the pulse. The rise time for IEC-HBM discharges is given in the ISO/IEC standards with a range from 0,7 ns to 1 ns. CM discharges show rise times less than 0,5 ns [4].

Due to statistical effects during formation of the arc it is difficult to give an exact rise time per discharge voltage. With increasing approach speed the rise times become statistically shorter [5]. At lower charging voltages the statistical effects becomes more stable. Figure 4 shows the average (150 discharges per voltage) rise time of a CM discharge into a 25 Ohm test structure protected by 10 nF. The rise time of the discharge above 2750 V is similar to an IEC-HBM discharge. Voltages above 2500 V are not considered in the following due to the affinity to the well known IEC-HBM discharge.

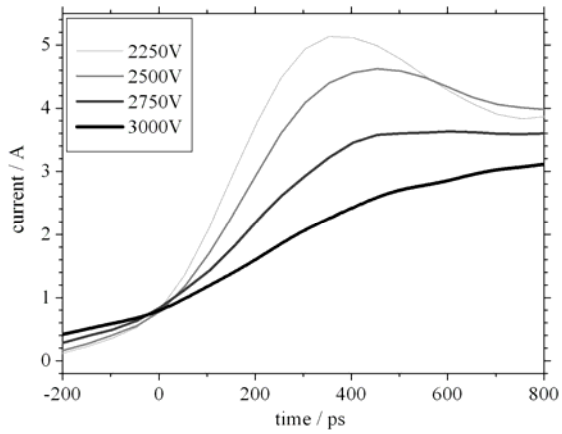

Figure 4: Cable discharge rise time with different voltages

VI. Discharge Characterization

The simulation models for the wire discharge are based on [6]. Corresponding to the measurements a discharge path with RC circuit was chosen. Figure 5 shows a possible simulation setup with a charged wire which is discharged into a PCB with a protection capacitance.

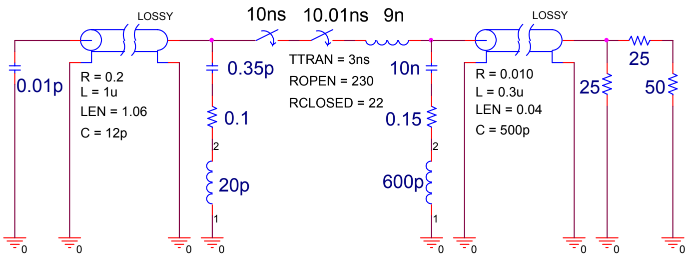

Figure 5: CM discharge simulation setup with a charged wire, which is discharged into a test board

A. Pulse Width

The discharge pulse width of a charged wire depends on the wire length [6] and can be calculated with:

$$t_{pulse} = \frac{2 \cdot l_{wire} \cdot \sqrt{\varepsilon_R}}{c} \tag{4}$$

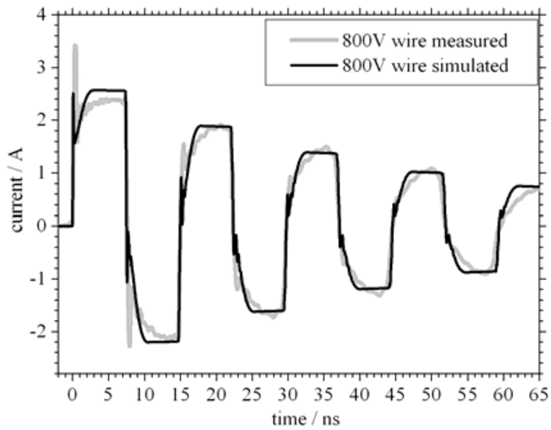

Figure 6: Measured and simulated CM discharge into a test structure.

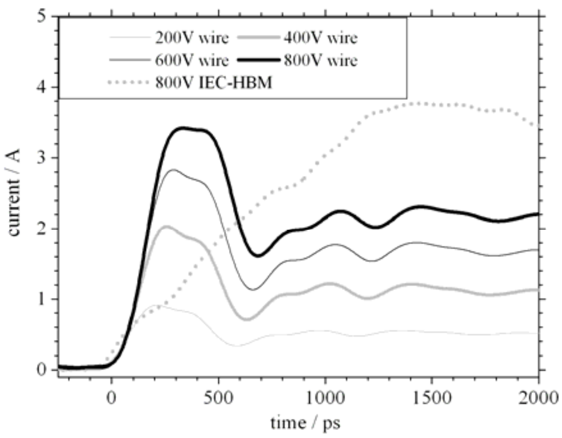

Figure 7: Comparison of a CM and an IEC-HBM discharge rise time

Depending on the impedance ratio of the wire and the discharge path several reflections may occur. Figure 6 shows a measured and a simulated CM discharge into the test structure (described in IV).

B. *Rise Time*

The rise time is mainly limited by the connection inductance. Figure 7 shows the rise time of several CM discharges compared to an IEC-HBM discharge (800 V, 330 Ohm, 150 pF) into the same test structure. The rise time of the CM discharge is about 5 times faster than the IEC-HBM discharge.

C. *Overvoltage*

The fast rise time of the discharge leads to a voltage spike after the protection capacitor.

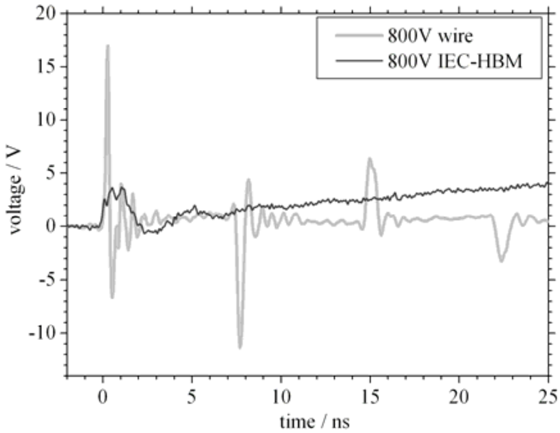

Figure 8: Comparison of a voltage spike on an IC input pin caused by a CM and an IEC-HBM discharge

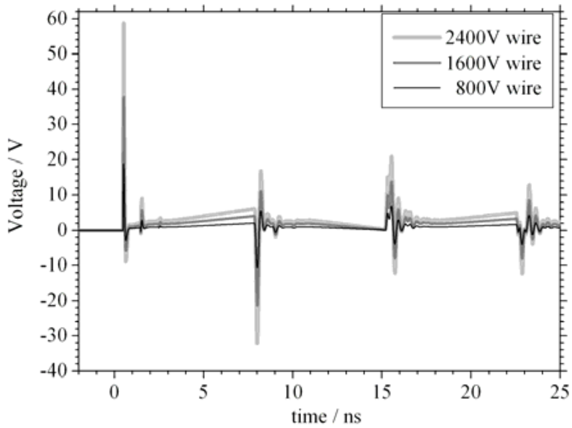

Figure 9: Simulation of a voltage spike on an IC input pin caused by a CM discharge

In Figure 8 the resulting CM voltage spikes measured at the IC structure and an IEC-HBM discharge (800 V, 330 Ohm, 150 pF) are compared. The voltage spike of the CM discharge is around 5 times higher than the IEC-HBM discharge. This behaviour correlates to the measured rise time of the discharges. Critical voltage spikes above 40V can occur depending on the discharge voltage. Figure 9 shows the simulation of a CM discharge into a 25 Ohm IC input pin protected by a 10 nF capacitor. The voltage spikes on the IC input exceed a voltage limit of 40 V.

VII. Discussion of Severity based on Failure Models

A. *Energy failure model*

The discharge energy of a CM discharge into a device can be approximated with the assumption, that no energy is radiated and

$$C_{protection} >> C_{wire}$$

The energy in the wire can be calculated.

$$E_{pulse} = \int U_{wire} \cdot I_{wire} dt$$

$$E_{pulse} = U_{wire} \cdot \int_0^{t_{pulse}} \frac{U_{wire}}{\sqrt{\frac{L_{wire}}{C_{wire}}}} dt$$

$$with \ (4):$$

$$E_{pulse} = U^2{}_{wire} \cdot \sqrt{\frac{C_{wire}}{L_{wire}}} \cdot \frac{2 \cdot l_{wire} \cdot \sqrt{\varepsilon_R}}{c} \qquad (5)$$

Figure 10 compares the calculated discharge energy of an IEC-HBM and a CM discharge into a 50 Ohm test structure. The discharge energy of typical wire configurations exceeds the energy amount of an IEC-HBM discharge. The dotted line shows the voltage level to reach the energy amount of an 8 kV IEC-HBM pulse (0,63 mJ). For a 2 m wire around 1,5 kV charging voltage is required to reach the energy amount of an 8 kV IEC-HBM discharge. Charging voltages up to 2 kV are visible for a wiring harness in an automotive production line.

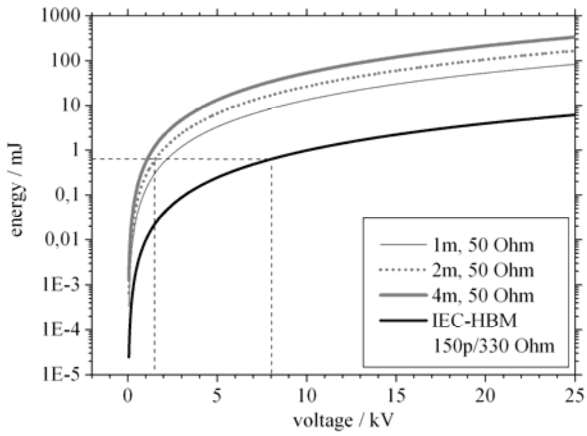

Figure 10: Energy of CM discharges (50 Ohm wire impedance) over discharge voltage, compared to an IEC-HBM discharge

B. *Overvoltage failure model*

The risk for the occurrence of a critical voltage spike at an IC pin is higher in case of the CM discharge than of the IEC-

HBM discharge. This behaviour can be lead back to the fast rise time of the CM discharge. Voltage spikes up to 60 V are possible.

VIII. Conclusion

The risk to be faced with a CM discharge in an automotive assembly line can be present for more than 30 minutes after a cable is charged.

The electronic devices of an automotive control unit can be destroyed by CM discharges. Standard filter structures close to the connector pins do not guarantee a reliable protection due to the fast rise times of the CM discharge events smaller than 200 ps. Parasitic inductances make filters inefficient. Voltage spikes beyond the destruction level of several IC structures can appear. Further investigation of protection concepts on IC level are necessary.

The energy amount of a CM discharge with a reasonable charging voltage is comparable to an IEC-HBM pulse. Additional investigations are required to work out the maximum discharge voltage which can occur in an automotive environment. Based on this data and on a typical wire configuration a common test standard to avoid CM problems in production will be suggested.

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