WHITE PAPER

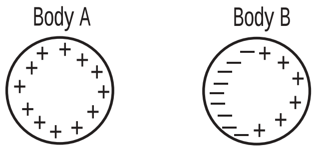
Electrical Discharge (ESD) Phenomenon Related to Telecommunications Cabling Systems

Introduction

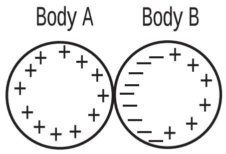
Prior to discussing the electrostatic discharge (ESD) phenomenon and its effects on telecommunications cabling systems, let's briefly review the process of static electricity generation, charge storage and discharge.

Static electricity is usually generated by the triboelectric effect which consists of the contact of two bodies (materials), of which at least one is insulating, and their posterior separation.

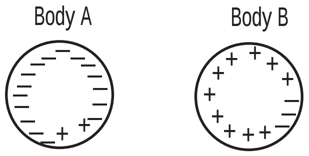
Some materials tend to acquire electrons on contact whereas other materials tend to give away electrons more easily, then, producing charge exchange between the two bodies. After the separation, one body will tend to be negatively charged and the other one, positively charged. This process of charge exchange between two bodies is shown in Figure 1.



a) Body A is positively charged and
Body B is a neutral conductor



b) Bodies A and B on contact



c) Body A tends to be negatively charged after separation and
Body B tends to be positively charged after separation

Figure 1: Triboelectric effect and charge exchange between two bodies

Charging can also occur by induction. In this case there is no contact between the two bodies. The inductive charging occurs when a charged body is placed in the neighborhood of a neutral or balanced conductor (from the point of view of charge distribution). Under this condition the electrostatic field will force the balanced charges present on the surface of the conductor to separate. The conductor will still remain neutral but with the same amount of positive and negative charges equally distributed along its surface.

Temporary ground of the neutral conductor causes some of its charge to leak away, thus leaving it charged without ever having been in contact with a charged body or material as depicted in Figure 2.

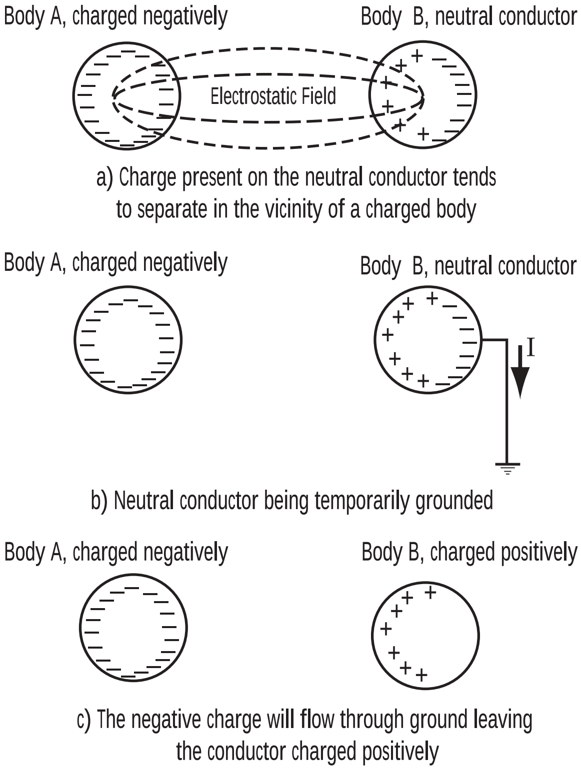


Figure 2: Process of charging by induction (electrostatic field)

The typical process involved is the charging of neutral body and its posterior discharge (electrostatic discharge) through a conductor to another conductor which may be connected to the ground. The classical ESD phenomenon is that charging of human bodies due to the contact to low conductive materials (carpet as an example).

Equivalent circuits to analyze the mechanism of charge and discharge of a human body due to the triboecletric effect are depicted in the Figure 3.

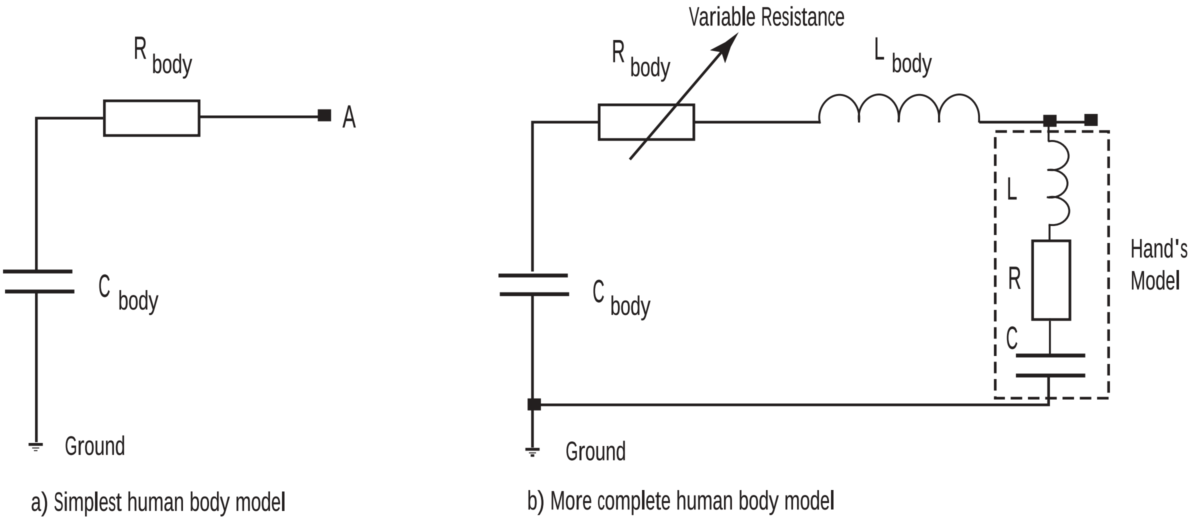


Figure 3: Human body models for the analysis of ESD

The model in (a) is the simplest human body model whereas the model in (b) is the more complete human body model for ESD study. The body capacitance to ground is typically 150 pF and the body resistance can vary from 500 Ω to 10 kΩ, depending on which part of the body the discharge will occur. Table 1 shows the relation between the part of the body involved in the discharge event and its associated resistance.

Part of the Body Involved in the ESD Event	Electrical Resistance
Finger's Tip	Approximately 10 kΩ
Palm of Hand	Approximately 1 kΩ
Metallic Object Held in Hand	Approximately 500 kΩ

Table 1: Electrical resistance as function of the part of the human body involved in an ESD event

Depending also on the values of the body resistance and due to the triboelectric effect the body may be charged to a potential of the order of several kilovolts that will be accumulated in its capacitance. It has been found that human bodies can be charged to a potential of more than 10 kV [1]. When the human body is placed in contact with a grounded conducting body or material, the capacitor will discharge generating a current that will flow to the ground resulting radiated and conducted interference. Usually there is a small arc rising from the human body to the other body or material characterizing the ESD phenomenon. The model depicted in (b) includes the hand model as well as the body inductance, which is not always included in the model, but is very important for the determination of the discharge current decay time (capacitor discharge time).

Hence, the capacitance of the body is responsible for its charge storage. Capacitance, charge storage and electrical potential of a charged body can be related by the following expression

$$C = \frac{q_b}{V_b} \qquad [1]$$

Where,
C is the resultant capacitance of the system (in farads [F]);
q_b is the electrical charge of the body (in coulombs [C]);
V_b is the electrical potential of the body (in volts [V]) for the static field case.

When two bodies exchange electrical charges through direct contact or by induction, the total amount of charge present in the system, before as well as after the charge exchange, will be fixed. Thus, one can say that the charge unbalance of the system is fixed. Due to the same reason the product $C.\ V_b$ is a constant. Placing the two bodies close to each other, the capacitance will increase and, consequently, the electrical potential will decrease. The opposite will also be true: separating the bodies the capacitance will decrease and the voltage will increase.

The typical ESD current waveshape is depicted in Figure 4.

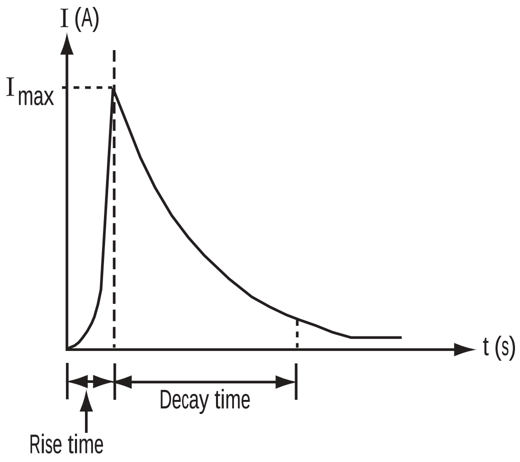


Figure 4: ESD current waveshape and the decay time detail

The rise time is determined by the value of the body inductance and the decay time is a function of the values of capacitance, resistance as well as the dielectric constant and the conductivity of the body. The current I_{MAX} is limited by the voltage value of the body at the moment of the discharge. The rise time is too small as compared to the decay time and the typical relation is 1:100; for a rise time of 1ns, the decay time will be approximately 100 ns.

Telecommunications cables

Transmission lines or transmission channels can be described in terms of distributed network parameters such as resistance, inductance, conductance and capacitance per unit length. Generally, the wireline channel can be represented by the series resistance and inductance per unit length along with the shunt capacitance and conductance per unit length. A model (designated Model T) for an approximate equivalent circuit for a length dx is shown in Figure 5.

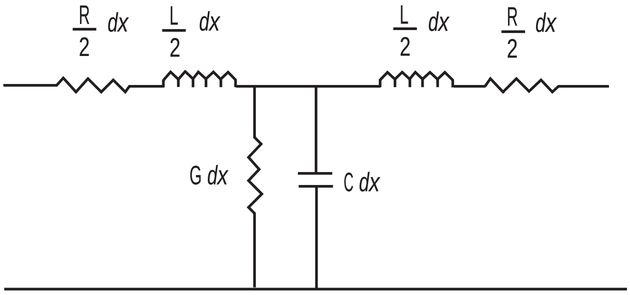


Figure 5: Model T for a wirechannel unit length, dx

The parameters resistance, inductance, conductance and capacitance are considered to be uniformly distributed along the channel length and they vary as function of the conductors geometry as well as dielectric properties of the materials surrounding the conductors. These parameters can be calculated by means of the Maxwell equations or other suitable mathematical techniques.

Usually, the dielectric material surrounding the conductor used to separate the two conductors in the same cable pair has a very good frequency response so that the conductance can be considered negligible. The value of the conductance can be assumed zero for the frequency range defined for Category 5e cabling systems (from 1 MHz to 100 MHz) without compromising model accuracy. Considering this assumption and rearranging the wirechannel model, the resultant model can be drawn as shown in Figure 6.

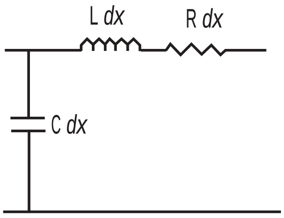


Figure 6: Another valid model used to represent a wirechannel without its conductance

It's important to realize that the wirechannel model is similar to the human body model for the ESD study, that is, both cases can be characterized by the same electrical configuration being composed by capacitance, resistance and inductance.

In order to represent a complete transmission channel (with a length l much longer than dx) using the T Model, a number of T sections (with dx length) have to be connected in cascade as depicted in Figure 7.

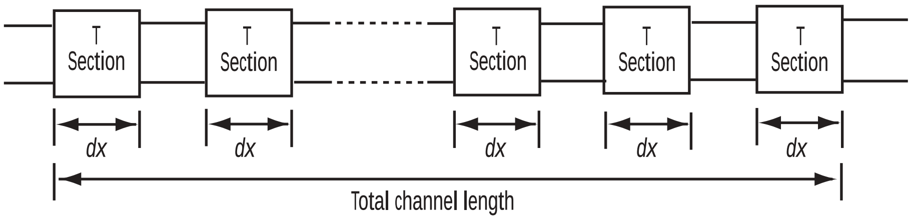


Figure 7: T sections connected in cascade to form a total cable length

Similarly to the case of the human body, the cable capacitance will be responsible for the energy storage in the cable and its subsequent ESD. The cable capacitance can be computed by the suitable summation of several T sections connected in cascade to model a wirechannel of length l. The resultant capacitance of a cable pair will increase as the cable length increases and will decrease as the cable length decreases (see the equivalent capacitance for different cable lengths in Figure 8).

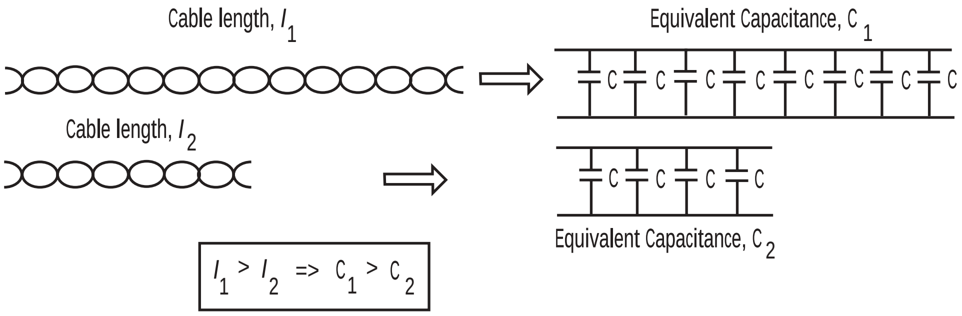


Figure 8: Cable capacitance increases as the cable length increases

Capacitance of telecommunications cables is also referred to as mutual capacitance. Cable manufacturers use this term to specify mutual capacitance values for their products and these values are frequently published in their products' catalogs. In order to minimize the crosstalk effect between pairs, cable manufacturers use different techniques to control the value of mutual capacitance of their cables.

For higher cable categories, lower mutual capacitance values are observed. In other words, Category 5e and Category 6 cables have lower capacitance than Category 5 and Category 3 cables. Table 2 shows the mutual capacitance values for several telecommunications cable types and categories for different cable manufacturers.

Table 2: Mutual capacitance for Categories 3, 5, 5e and 6 UTP/ScTP and FTP cables

Cable Manufacturer	Cable Type	Cable Category	Mutual Capacitance (pF/m)	Notes
Berk Tek	LAN Grade Cables	3	66	Non-plenum/ Plenum UTP cables
Harbour Industries	Plenum cables	3	65	Plenum UTP cables CMP/MPP
Genesis Cable Systems	Voice & data cables	3	56	CM rated/ Plenum rated UTP cables
Belden	DataTwist Three horizontal/ backbone	3	62.3	Non-plenum UTP cables
Berk Tek	Hyper-Grade cables	5	56	Non-plenum/ Plenum UTP cables
Berk Tek	Powersum cable series	5	56	Non-Plenum/ Plenum UTP cables
Berk Tek	Zero Halogen cables	5	56	UTP/ScTP cables
Commscope	Non-plenum cable series	5	56	Non-plenum UTP cables
Harbour Industries	Plenum cable CMP series	5	46	Plenum UTP cables
Harbour Industries	Plenum cable series	5	56	FTP (Foiled Twisted Pair) cables
Genesis Cable Systems	Voice & data cables	5	49	CM rated/UTP Riser rated UTP Plenum rated
Belden	DataBrite® Five	5	49	Non-plenum/ Plenum UTP cables
Berk Tek	LANmark 350	5e	44	Non-plenum/ Plenum UTP cables
Commscope	Ultra Plenum cables	5e	46	Plenum UTP cables

Note: All cables are 100 ohms/4-pairs/24 AWG

Table 2 (con't): Mutual capacitance for Categories 3, 5, 5e and 6 UTP/ScTP and FTP cables

Cable Manufacturer	Cable Type	Cable Category	Mutual Capacitance (pF/m)	Notes
Commscope	Non-plenum cables	5e	46	Non-plenum UTP cables
Harbour Industries	Plenum cable CMP	5e	46	Plenum UTP cables
Genesis Cable Industries	Voice & data cables	5e	46	CM rated enhanced UTP cables
Harbour Industries	Plenum cable CMP	6	46	Plenum UTP cables
Commscope	Ultra Media cables	6	46	Plenum/ Non-plenum cables ETL Type UTP
Commscope	Ultra Media Cat. 6 cables	6	46	Non-plenum UTP cables ETL Type
Belden	Data Twist 350	6	45.9	CM,CSA Non-plenum
Berk Tek	Unshielded LANmark 1000	6	44	UTP cables CMR Riser, CM Patch, CMP Plenum UTP cables

Note: All cables are 100 ohms/4-pairs/24 AWG

ESD Events on Telecommunications Cables

Charge storage in telecommunications cables can take place by the following mechanisms (isolated or combined):

- Conductive coupling;
- Electromagnetic coupling.

Charge storage due to conductive coupling can occur when the electrical potential of the equipment connected to the cable in one of their ends is higher than the electrical potential of the equipment to be connected to the opposite cable end (see Figure 9).

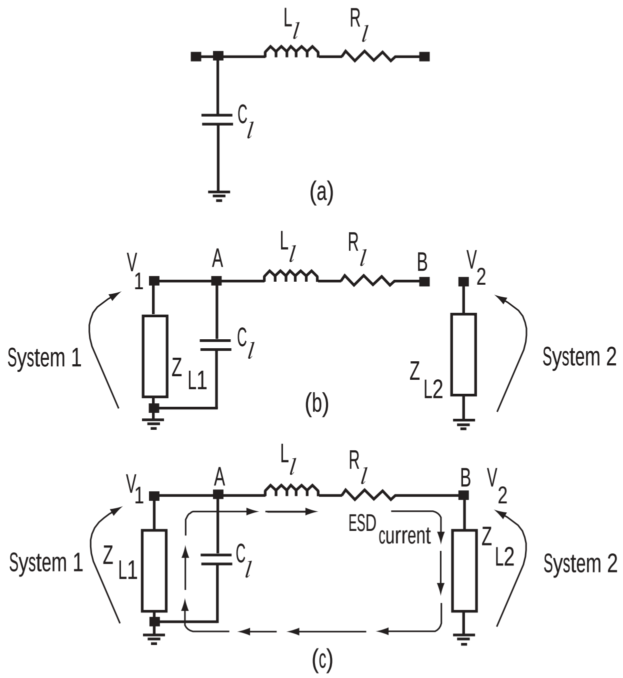


Figure 9: ESD current due to conductive coupling

Figure 9a shows the equivalent cable model for the cable length, l. Z_{L1} and Z_{L2} are the equivalent load impedances of active equipment of system 1 and system 2, respectively. V_1 and V_2 are the electrical potentials (voltages) of the load impedance of the systems 1 and 2, respectively (let's assume that $V_1 > V_2$).

Considering the active equipment (system 1) connected to the one cable's end (Figure 9b), the voltage at the point A will be the same as the voltage V_1. The equivalent cable capacitor, C_l, will then be charged due to this potential and the voltage at the point B will increase. Supposing that V_1 increases due to any circuit's failure in the system 1, the voltage at the point B will also increase.

When the cable is connected to the system B, in order to interconnect systems A and B, the accumulated charge in the equivalent cable capacitance, C_l (responsible for the voltage at the point B) will create an ESD current flowing through the equivalent load impedance of the active equipment of system 2, Z_{L2} (Figure 9c). Depending on the voltage level at point B at the moment of the electrostatic discharge as well as the protection methods implemented in system 2's circuitry, the intensity of the ESD current will be high enough to cause some damage to it.

The electrical potential at the point B can reach values of several kilovolts depending on the channel length and the cable's mutual capacitance, largely based on the cable category. In the case of electromagnetic coupling, the discharging process will be the same as in the case of conductive coupling.

The only difference is that the charging process will occur due to the electromagnetic field present in the environment where the cable is inserted.

ESD protection and control

Due to many similarities with electromagnetic compatibility (EMC), ESD protection and control methods are similar to those used to control electromagnetic interference (EMI) and are listed below:

- Common mode chokes;
- Overvoltage clamping devices (as capacitors, varistors, avalanche diodes, etc.);
- Conductivity control of working surfaces;
- Humidity control of rooms;
- Cable shielding;
- Cable bypass filters.

From the list shown above, the only method associated directly to cabling systems is the use of cable shielding. This method is very efficient but not necessary when used with active equipment with good interface input protection as well as suitable circuit design and PCB (Printed Circuit Board) layouts as part of the telecommunications network in a given installation. Table 3 below shows the voltage measured between the cable conductor and ground in one channel end when a discharge of 10,000 V occurs at the far end. In all situations presented in this table the shield has a 360° bond to the equipment box connected to the functional installation grounding. The shielding at the opposite end varies.

Shielding Connection	Measured Voltage
No shielding or not connected to the equipment cabinet	500 V over
Drain wire ground connection	Approximately 16 V
Shielding soldered to the connector in contact with equipment cabinet	Approximately 2 V
Shielding soldered to the connector with 360° contact between the connector and the equipment cabinet	Approximately 1.25 V
Shielding clamped directly to the equipment cabinet with 360° contact without connector	Approximately 0.6 V

Table 3: Effect of shielding connection on ESD event[1]

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[1] Palmgren, 1981/Henry Ott, 1988

The active equipment protection can be easily implemented using the common mode choke technique and overvoltage clamping devices. The time response of the system protection is its key factor as a typical ESD event time duration is too short (typically more or less 100 ns).

Even so, if a spontaneous accumulation of charge occurs, this situation can be prevented by terminating unused network ports with shorting plugs or providing connecting hardware with shorting contacts that are physically moved out of contact by mating up the connection.

Conclusion

There has been no change in the cable insulation when going from Category 5 to 5e or 6. The materials are still the same that have been used in this industry for several years. Thus, the incidence of ESD in high performance cabling and associated active equipment is less now than in the past.

ESD currents generated by Category 5e and Category 6 cables in an electrostatic discharge event will be less harmful to the disturbed circuit than those generated by lower cable Categories in electrostatic discharge events.

The electrical potential (voltage) measured at the input of the disturbed circuit due to the static charging will be also lower for higher cable Categories.

The other factor of concern on the side of network equipment is that the susceptibility of this equipment to ESD is increasing due to the implementation of new transceivers employing more PHY chip density. The implementation of new electronics without suitable changes on the front-end regarding to the ESD susceptibility will also lead the electronics to damage due to the electrostatic discharge phenomenon.

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