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ESD instructions for electrical workshops

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The goal of this thesis is writing instructions about Electrostatic Discharge (ESD) protection and how to build Electrostatic Protective Areas (EPA) for an electrical repair workshop use. I am writing these instructions for a company called ABB.

ESD protection is needed, when working with any kind of electronics. ESD can damage a sensitive component or a device, making it malfunction, break down completely or defect it so that it will break down prematurely. In this thesis I will explain different ESD control methods and get more into how ESD occurs and why.

By doing research from online and literature, the goal was reached. Proper ESD safety instructions were made.

Keywords	ESD, EPA, Static

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Abbreviations

CDM	Charged Device Model
EOS	Electrostatic Overstress
EPA	Electrostatic Discharge Protected Area
ESD	Electrostatic Discharge
ESDS	Electrostatic Sensitive Device
DUT	Device Under Test
HBM	Human Body Model
MM	Machine Model
RH	Relative Humidity

1 Introduction

Electrostatic discharge (ESD) is a common issue in the industry field, almost any conceivable industrial process can cause an ESD event. ESD can cause irreversible damage and this is why ESD protection is essential. Especially in the field of electronics and in industry which manufactures and works on electronics and electric devices. Components and integrated circuits that sensitive to ESD affected by it can break down completely or can be degraded and start malfunctioning later, even passing tests without any issues. Broken components and circuits increases manufacturing costs, which also affects to product quality and reliability. As technology advances, electronic devices and what is inside of them become more complex and is fitted in smaller size, their sensitivity to ESD in general increases. Typically companies have their own ESD safety instructions but not everyone is aware of the problems it may cause. To put this in perspective there are many different items, that no one could think of, in workplaces that can carry high enough charge to damage a circuit. There might be certain tools on your table that can carry a destructive charge on them. [1].

Therefore ESD being a noticeable problem in the industry field, there is ESD Association that provides ESD standards. ESD standards are collaboration between all organizations and individual affected by these standards. ESD standards provide information on requirements, testing methods and technical reports on all ESD related issues. [4].

Electrostatic discharge protected area (EPA) is also a fundamental part of ESD, because it is a whole area which is protected from static electricity. These areas are built in factories and repair workshops for ESD safe working ground. [4].

The goal of this thesis is to provide good enough instructions about ESD protection and information on EPA for ABB's repair workshops and for the field service engineers. But also to any other electrical repair workshops that have to take ESD protection under consideration.

2 Theoretical Background on ESD and EPA

To get a better grasp on electrostatic discharge and how to control it, understanding how electrostatic charge occurs, is needed. Electrostatic charge is defined as charge at rest. Static electricity is all around of us and is a natural phenomenon. A material with no static charge has equal amount of positive charges being protons and negative charges being electrons. For static electricity to occur, that material needs to lose or gain electrons. By bringing two materials into a contact and adding friction, a chemical bond has been created between these materials, allowing electrons to move from one material to another. This happens because charges tend to move from one material to the other to equalize their electrochemical potential. After separating these materials from one another, some amount of electrons have left from one material and the equal amount of them has been gained in the other. Both materials are now electrostatically charged, the one which loses electrons is now positively charged and the other one gaining electrons is negatively charged. This event is known as the triboelectric effect and is the most common way to create an electric charge on a material, see figure 1. When positive or negative charge builds up on an object, its electrical charges are in imbalance within or on the surface of the object. The charge will remain on the object until it can transfer away in a way of an electric current, electrical discharge or ESD event. Grounding the object will neutralize the charge. Any other electrical conductor works too, because a conductor allows the flow of electrical current in it. Other ways of neutralizing an electrostatic charge is by bringing the charged object to a region with opposite polarity. Imbalance of the electrical fields cancel each other out. [1], [3], [4].

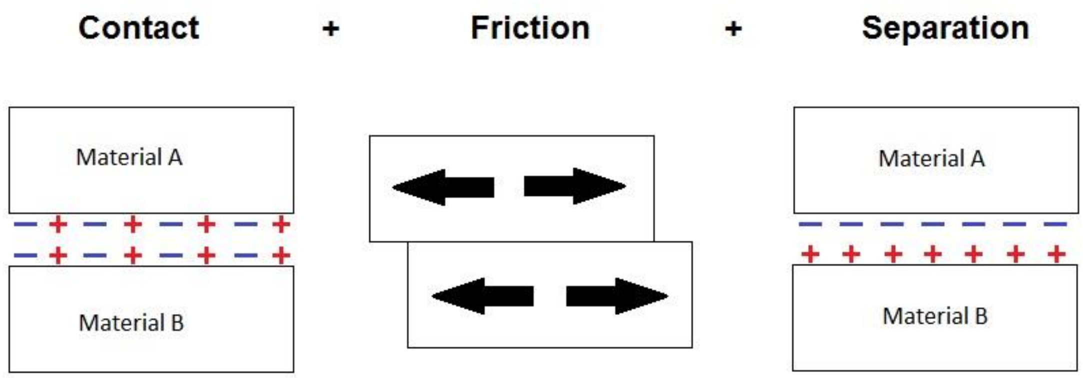

Figure 1. The triboelectric effect.

Static charge created by the triboelectric effect has many other variables affecting the amount of the charge. The quantity of an electrostatic charge is measured in coulombs. The quantity of an electrostatic charge on a certain object is denoted as “q”. The electrostatic charge can be calculated by the product of the capacitance of the object, denoted as “C”, and the electric potential “V”, on the object. [1].

$$q = C * V$$

Equation 1. Electrostatic charge.

Variables that affect the amount of charge are such as, area of contact, speed of separation, relative humidity, roughness and shape of the materials’ contacting surfaces and chemistry of the materials. Materials that tend to lose or gain electrons in contact, are put into a list known as the triboelectric series. Triboelectric series helps to see how different materials tend to charge on contact and separation. This list only works as a general guide, because there are a lot of variables making it hard to be controlled to get same results repeatability. Material which is closer to the top of the positive charge list charges positively and the other negatively. Further away the materials are from each other on the list, the electrical charge transferred between them will be greater and the attraction between the materials is stronger. If the materials are near each other on the series might not build any charge or can even charge opposite polarity than the list shows, see figure 2. [4].

POSITIVE CHARGE	NEUTRAL	NEGATIVE CHARGE
Dry Human skin	Cotton	Wood
Leather	Steel	Amber
Rabbit Fur		Hard rubber
Glass		Nickel, Copper
Quartz		Brass, Silver
Human hair		Gold, Platinum
Nylon		Polyester
Wool		Saran Wrap
Lead		Polyurethane
Fur		Polyethylene
Lead		Polypropylene
Silk		Vinyl (PVC)
Aluminum		Silicon
Paper		Teflon

Figure 2. A triboelectric series. [12]

The ways how static charge builds up, can be rather complex. Everything around us affects to the generation of the charge and practically everything can be triboelectrically charged, even the tiniest impurity particles in the air. Materials' chemical and physical characteristics determine how much charge is generated. [3].

Whenever an object builds up an electrical charge, the amount of its electric potential varies. The electric potential can be calculated by the potential energy "E", per unit charge "q".

$$V = \frac{E}{q}$$

Equation 2. Potential Energy

Value of the electric potential depends how strong the charge is and how much energy there is in that charge. Different scenarios generate various amounts of electric potential in each case. Also the relative humidity affects to this. Humid air reduces static electricity. More humid it is, the more water there is in the air. Water of course conducts electricity. So an electrostatically charged object has water molecules on it that shares its electric potential and reduces it. We will talk about conducting materials and conduction further in the text. In this next table, there are few examples of electrostatic generation and the possible potential levels in dry air and humid air, see table 1. These numbers are not exact. Because there are many different variating elements, but these give a common knowledge how much energy certain everyday scenarios can produce. [8].

Table 1. Examples of static generation. Modified from [2], [4]

Methods of generating static electricity.	Electric potential, V	
	RH 10-20%	RH 60-80%
Walking across carpet, human body	>30 000	>2 500
Separating bubble wrap from a bubble wrap roll	>20 000	>3 000
Mechanical packing/wrapping with plastic wrap	>5 000	>1 000
Standing up from a polyurethane foam chair	>5 000	>1 000
Walking on a PVC-coated floor	>2 000	>600
Walking with conductive shoes on, on a static dissipative floor	<50	<5

There are materials that insulate electricity because of their high electrical resistance. Impurities and surface condition of the material have a vast impact on the surface resistance of an insulator. Also temperature have a significant role in insulators, as the temperature increases resistivity decreases. Different materials of course have different electrical characteristics and these affects in the resistance of an insulator. Insulator's volume resistivity varies between mega (10^6) ohm metres (Ω*m) to tens of tera (10^12) ohm metres. Surface resistivity is measured by ohm per square, so an area of the surface has a certain resistivity value. It varies between giga (10^9) ohms per square to even beyond tera ohms. These insulating materials can charge up easily by static electricity, but the electrons does not flow across its surface or through its volume. An electric insulator can carry a huge charge on it by losing or gaining electrons. And because its high electrical resistance prevents the flow of electrons, it can have both negative and positive charges on it, just in different places on the insulator. If the opposite charges are near each other on the insulator they might cancel each other out, but in most of the cases the charge can stay there for a long period of time. Even with an electrical conductor inbound the charge will take a while to discharge, because there are only a small number of charge carriers which can carry current and by this discharge the insulator. [9].

Conductive materials on the other hand are materials that have low electrical resistance, which allows electrons to flow easily. Conductors' resistance and conductance depends on length of the conductor, the cross-section area of the conductor, electrical conductivity and electrical resistivity. The resistance varies from hundred ohms to hundred kilo (10^3) ohms. Temperature also has a relatively small factor in this one. A conductive material once charged, can only be either positively or negatively charged. Fast flow of electrons will try to keep the conductor at neutral state. Bringing a neutral conductor in contact to a charged one, the neutral conductor will even the electrical imbalance within the charged one rapidly. Also connecting conductor to any electrical grounding point, will neutralize the charge. [4], [10].

A mixture of these two materials is called static dissipative material. Its electrical resistance is somewhere between insulative and conductive materials. Electron flow in dissipative material depends mainly on its resistance. If the compounds resistivity is closer to insulative material's resistance, the electron flow will be really slow and it will act like and insulator, and if closer to conductive material's resistance it acts like a conductor. Static dissipative materials can also carry an electrical charge and can be charged triboelectrically. Dissipative material works like a conductor, it will try to even the charges within if there are a neutral conductor or grounding point. The transfer of charge, takes longer compared to same sized conductive material, but faster than insulative material. Because of this, a static dissipative material is widely used in protection for ESD. It conducts excess charge quickly, but the conductivity is not too high to be able to create high enough currents to be harmful or swift discharges. [1].

If a material is electrically charged, this means it has an electrostatic field around it. These electrostatic fields can be measured and calculated. Electric field strength "E" can is equal to force, denoted as "F", divided by the charge, denoted as "q".

$$\bar{E} = \frac{\bar{F}}{q}$$

Equation 3. Electric field strength.

Electric field strength “E” and force “F” are vector quantities. Charge “q” does not have a line of force associated with it. If the line of force from the electric field is away from the charge it is positive and if towards then negative. The electric field strength decreases by the distance. [4].

Conductive objects can be polarized by bringing them in the region of a charged object’s electrostatic field. This phenomenon is called induction. On the surface of the conductive object the electron will either repel away from the electric field or be attracted closer to the source of the electric field. If the field is negative, negative electrons will be pushed further away from the source, and if the field is positive then it will attract the electrons closer, trying to even the positive charge of the source. In either case the conductive material is now polarized, it has negative charge at one end and positive at the other. Now if we connect this conductive material to a grounding point, the charge will try to fix electrical imbalance within and the charge will flow from or to ground. After disconnecting conductive material from the ground and removing the electrical field, an electrical charge will remain on the object. This is a way of generating an electric potential on an object, with the help of electrostatic fields. Only conductive and dissipative materials can be charged by induction. An electrostatic-sensitive devices can often be damaged by this, if the device is in the field of excess charges and is then touched with a metallic tool, allowing the excess charges to burst into the device through this conductor. [3].

2.1 ESD

Electrostatic discharge, as can be reasoned from the name, a swift transfer of static electricity by a high electrostatic field. So something that has an electrical charge quickly loses it by discharging the excess charge into something. Bringing and electrically charged object near an electrically neutral object, will charge the neutral object. Neutral object will be either positively or negatively charged, depending on the charged object’s polarity. In contact the dielectric between them breaks down and the charged object discharge to the neutral object. This will create an electric spark, which is usually visible to human eye, but in some cases the electrical charge is not high enough to be seen. Over 3000 volt discharges can be felt, over 4000 volt discharges can be heard and over 5000 volt discharges can be seen. When driving a car you can notice this. During the travel, you and the seat of the car will start to charge electrically by your movement and the two different materials rubbing each other. You are now positively or negatively charged depends on the material you are wearing, When you reach your destination and get out of the car, you might be able to feel a zap when touching car's door or frame, the electric charge that has been charging up while you were driving has now discharged. [9].

ESD can change the electrical characteristics of a semiconductor device which damages the device. Sometimes ESD event may cause a temporal malfunction or a failure on electronic system, not breaking it. Charged surfaces can work as magnets for impurities by attracting and holding them, making removal of the particles difficult. These impurities can carry an electrical charge of their own and possibly damage highly sensitive components, such as silicon wafers or even electrical circuitry. [9].

As mentioned before, ESD damage can be instantaneous or an electrostatic sensitive device "ESDS" has been exposed to an ESD event and will break down later, without showing any symptoms before. It is good to remember to keep the ESD protection on from manufacturing to the moment at a repair site handling electronical devices. If there is a break in the ESD protection somewhere between that time, no one can guarantee that it should work properly. [10].

An ESD event can do such a damage that an electronic device will instantaneously stop functioning, this is often denoted as catastrophic failure. Such damage is caused by high burst of electricity and the deficiency of shielding against high spikes of electricity. High volume of electricity in a burst can melt metal, fry components, breakdown junctions any of these can be a cause for an electronic device to stop working. [2].

There can also be scenarios where an electronic device is exposed to an ESD event, but will keep functioning like intended and breakdown later. This kind of scenario is usually referred as latent defect. These are hard to identify, because a device with a small defect can pass all the necessary tests, but still be partially degraded and breakdown prematurely. These defected devices are costly to repair and can create personnel hazards for the person who is plugin in the device. These matters are also costly for the company producing them, money and reputation wise. [2].

A catastrophic failure is rather easy to spot via tests. There are different kind of tests for different kind of features, but everything is tested from components to electronic devices before shipping. These tests will prevent the shipping of faulty devices. Latent defects being really hard to detect, can pass these tests and move forward without any prove of deficiency. Maybe as the technology advances, we have the correct tools to be able to spot these invisible defects someday. [2].

There are several different causes for ESD events, in this report I have talked about static electricity and electrostatic induction. These events are the cause of an ESD damage. An ESD event that causes damage can be an electrostatic discharge to the ESDS, an electrostatic discharge from the ESDS or by an electrostatic induction, meaning electrostatic fields and their disturbance by an ESDS. Electrostatic discharge's potential varies by different variables during ESD event. ESDS might be damaged by the discharge if it has not enough safety measures build in it. The energy transferred during the ESD event must be evenly distributed along the circuitry otherwise it will cause an electrostatic overstess "EOS" event, which also damages the device. Other factor is the voltage level of the charge that varies from few volts to hundreds of kilo volts in some extreme cases. To bear in mind, many of the ESD events occur without any notice, like a visible spark or a crackling sound. As small as 10 volts discharge can damage some equipment like disc drives and circuitry inside of them. How much energy of the discharge and the voltage the device can take and when it fails is known as the device's ESD susceptibility. [2], [4], [9].

A direct electrostatic discharge from charged conductor to an ESDS is one of the very common ESD events that causes damage to a sensitive device or component. Human body works like a conductor and can charge even up to 30 000 volts, when walking across carpet and the relative humidity in that room is between 10% and 20%. So a charged human body can work as a carrier of that electrostatic energy. Bringing a hand near or in a contact with the sensitive device will allow all that energy to discharge, because the human body is at certain potential and in most of the cases the device is at very different potential allowing current to flow. Discharge will happen because the charge on a human body is trying to balance the potential different between these two. At the discharge human body loses all that excess charge and will be dissipated over the device and damaging it in most of the cases. There are tests using this same method but with built circuitry to measure and test ESD susceptibility. It is called the Human Body

Model “HBM”. Also a metallic tool can work as a conductor and do the same damage, in this case the event is called the Machine Model “MM”. There are more information about HBM and MM later in ESD measurement section. [2], [4], [9].

An ESDS can also carry an electrostatic charge which can be discharged to a conductor. An opposite ESD event of the previous one is another way of causing ESD damage on sensitive devices or components. Handling, packing, moving are all contact and separations that accumulate charge on materials. A sensitive device or component on the way to packing and inside a packing material can start building up a static charge by all this. Bringing this charged device near a conductor will then discharge and by the swift change of potentials usually damage the ESDS, causing malfunctions and even breakdowns. This event is also modelled into an ESD susceptibility test and is known as Charged Device Model (CDM). [2], [4], [9].

Of course as the technology advances and actual human assemblers are less needed the HBM scenario is not that relevant. But in a field work it is wise to remember that you have to have everything set up before touching an ESDS. Still with automated production lines are getting more popular, the ESD is still a common problem because a device may become charged as it is sliding down a feeder and then is in contact with something that is very conductive, resulting an ESD event. [2], [4], [9].

An electrostatic induction that also charges materials can be a direct or indirect source of ESD damage. Whenever an object has accumulated a charge, it also has an electrostatic field. An ESDS inside this electrostatic field will be charged through induction and be polarized as well. When the charged ESDS is connected to a grounding point it will discharge similarly as the CDM event was explained. [2], [4], [9].

As mentioned in introduction, standards provide certain guides how to implement ESD protection in needed place. There are three different categories of these standards. First one are those that provide ESD control program info and requirements. In my research ANSI/ESD S20.20 Electrostatic Discharge Control Program Standard stood up and is being referred to in many different sources and texts. It is a standard that provides administrative and technical information about ESD protection and it has different value limits that should be followed. It was first published in 1999, and was created to provide much needed information to companies on an ESD control program and how to design, develop, implement and maintain it. The ESD control program is to have guide lines how to protect ESD sensitive electrical equipment, devices or components from being damaged by ESD greater than or equal to 100 volts by human body model or 200 volts by charged device model. The standard can be applied in any activity that may be susceptible to ESD damage. This standard provides all administrative and technical requirements that are needed to build an electrical repair workshop. Administrative requirements are, ESD control program plan, training plan requirement and compliance verification plan. And the technical requirements are, grounding and bonding systems, personnel grounding, protected areas, packaging, marking, equipment, handling. Audits are occasionally performed to verify compliance with these requirements. Audits are efficient way to see that the ESD protection is up to date and the personnel is following the given guide lines. [4].

A second standard group is about packaging requirements and grounding. The last group has standardized test methods and documentation about all already conducted tests. [4].

ESD susceptibility is determined by testing and measuring how much an ESDS can dissipate discharged energy at ESD event and how high voltage levels it can withstand. Tests are made by the previously explained ESD event models, according to the wanted situation. To see how much a certain component or a device can handle when there is a person working, HBM event could be used. This would help to define the ESD limits and the correct safety measures. There is no idea of spending millions on correct ESD control protection, if there is a reasonable set of rules to follow and will do the same job, without costing a fortune for the company. These models are only test procedures to help choosing the right way to approach same kind of situations, they are not exact copy of a real time event with other variables around too. There will be more information about the ESD testing later in this report. [2], [4], [9].

Everything is getting smaller and more complex in digital way, at the same time ESD problems are increasing, because these smaller components and circuits tend to be more sensitive to ESD damage and need even higher precautions with them. Already now there are many items are only susceptible for hundred volts or even below. And as seen from table 1, those numbers are easily met if there is no ESD protection taken under consideration. [2], [4], [9], [10].

2.2 EPA

Electrostatic discharge protected area “EPA”, means an area that has same electric potential between all surfaces, ESDS, people and tools. An EPA is equipped with ESD controlling items and materials. Having same electric potential between different objects minimize the risk of an ESD event and prevent sensitive devices and components being damaged. In ESD protected areas insulating materials are not used, their electrical characteristics are not suitable there. As mentioned before even grounding an insulative material will not neutralize the charge immediately and those can build up a huge charge which is a risk for ESDS. Instead dissipative and conducting materials are used and everything inside an EPA is linked to the ground to equalize electric potential between them. ESD protected areas are usually clearly shown by signs, such as in figure 3. [1], [2], [4], [8].

Figure 3. A typical EPA sign. [13]

In field work, working on a device where you are not on an ESD protected area it is possible to build a temporary EPA. An ESD mat for example is made out of static dissipative or conductive material, same material that is used in ESD protected areas. This is an essential part of a temporary EPA, when a person and the device under maintenance is on the mat, they share the common ground. There are several other ways to be protected from ESD and I will tell more about those later in this report. [1], [2], [4].

3 ESD Protection

There are many different aspects that needs to be taken under consideration In ESD protection in the field of electronics. ESD control methods and guides are presented in international publications, ESD standards and ESD protection recommendations. These publications have the needed information how to proceed towards ESD safe work environment and what else is good to know. [4].

The basic approach to ESD protection is to neutralize the chance for a current to flow, by bringing all elements on site to same electric potential. This means everything from a simple screwdriver to a human working on electronics. Money is also fundamental part when considering options between protective materials and methods. It is important to know what is needed. Some protection measures might cost more than they actually provide money. While planning a new electrical repair workshop or such, it is necessary to think if all measures must be included and how much money that will cost and maybe save. Key concept on ESD protection is having fundamental protection measures under control and that the product reliability is high. For an amateur setting up correct protection measures can take a long time, but when working with a big company, they usually provide their point of view towards ESD and can give help building an electrical repair workshop. [1], [2], [4], [9].

Generally speaking, ESD protection starts with the design. Electronics today are expected to last longer and work faster. Also the designs and implementations are getting smaller, their sensitivity to ESD is put to the test. When designing an electronic device effects of ESD events need to be accounted. An electronic device will most probably come in contact with ESD at some point of its lifecycle. It is important that the device is designed so that it will not break down from the slightest discharge. Protection needs to be built already in circuitry. Circuit must be able to tolerate high peaks of voltage and current. Dissipation is the main goal here, even dissipation of these energies provides safety against an ESD event. Providing sufficient ESD protection on a device will also cut manufacturing costs and increase product reliability. Design is not alone an efficient ESD protection method, it is just a precaution for further use, but whenever an electrically sensitive components is being handled environment is the main concern. [2], [4], [9].

ESD protection goes through the whole lifecycle of an electronic device, from production to assembly to its final installation and use. And it is important to never break the ESD protection chain. A break in chain means a possibility to an ESD damage. [2].

There are ways to spend too much time and money at designing on ESD protection. The needed level of protection varies in each case. HBM, MM and CDM are good ways of conducting tests for ESD susceptibility and figuring out what level of ESD protection is needed.

Having an EPA for manufacturing, repair work, storage or any other occasion with ESDS is a strong ESD control method. At an EPA high charging materials such as insulative materials are banned. There is no real way getting rid of all static electricity, but a common ground and same electrostatic potential between everything inside an EPA is important. Also by reducing accumulation of electrical charges, with conductive or dissipative materials, the chance of an ESD event gets lower. [2], [4], [9].

Different ESD protective materials carry a considerable role in ESD protection. ESD protective materials are used inside and outside of an EPA. Protective materials provide needed protection to ESDS for handling, transportation and storing. Shielding an ESDS from generating a charge and be discharged to. When an ESDS is leaving an EPA it should have a proper discharge shielding around it. For example there are antistatic bags, made of a conductive plastic to prevent any ESD damage during the transportation or storing phase. [2], [4], [8].

Not only ruling out the factors for possible ESD events is not everything in ESD protection. Personnel needs to be trained also. If the personnel does not understand the meaning of ESD or how to work in EPA, the protection is not guaranteed. ESD training and processes are important to know and not taken as a granted. Periodically organized ESD audits and measurement of protective materials are needed. Checking that everything works as intended works as a proof of quality. [2], [4].

At electrical repair workshop it is important that all the personnel have the knowledge on ESD and workstations meet the needed standards on ESD protection. ESD protective areas must be signed clearly and that those are for authorized personnel only. Conductive ESD shoes and cotton clothes are also mandatory.

3.1 ESD Protective Materials

ESD protective materials are made of non-insulative materials. These can be compounds of different materials but their electrical properties are always non-insulating. Packing materials are usually made out of anti-static material. Anti-static material reduces already built up static electricity or it dampens a discharge. Conductive and dissipative materials are used in ESD garments, an EPA flooring and in ESD mats. Carbon powder or carbon-fiber materials are used in applications where high temperatures are taken into account. [1], [2], [4].

Anti-static materials are usually made out of plastic materials that are highly insulating. But the plastic is saturated with an anti-static substance. Having an anti-static coating and with the help of humidity in air the material is highly resistive, but still conductive enough to reduce or eliminate buildup of static electricity. Circuit boards and such are usually wrapped in anti-static bags, there are two different kind of compounds that are used. Other one is dissipative and other conductive. [2].

Dissipative anti-static bags are made as explained above. This material prevents static electricity to be buildup. In transportation boxes vibrate and can triboelectrically charge, this material will prevent generating its own charge. However if an electrically charged object touches the bag, it can damage the bags contents. Dissipative chemical layer colors the bag pink. If there compound contains any traces of carbon it is black. Carbon provides a partial shield, but it is not something to rely on. Unpacking ESDS it is important to be grounded so that the body cannot damage the contents of the bag. [2].

Conductive anti-static bags have a conductive metal layer and a dielectric layer of plastic. These are also coated with a dissipative coating. With the metal layer inside, contents inside are more invulnerable to ESD. More sensitive components and circuit boards are packed in these. The metal layer does not endure everything and can be worn out in time. Color of these bags comes from the metallic layer, being silver or gray. [2].

Anti-static bubble wrap and packing foam also exists, and have the same color attributes as the anti-static bags. These packing materials protects also from mechanical damage. [2].

3.2 Protective Gear

ESD protective gear are made to prevent electrical damage to devices and components. A person at a worksite is one of the greatest sources of static charge. This is why protective gear is widely used in the field of electronic industry. There are anti-static footwear, dissipative footwear, anti-static wrist straps, wearable garments that have conductive threads in them, anti-static mats and such. [2], [4].

Footwear that will not insulate a human body from the ground are the best way to prevent a human from charging. With insulative shoes, human body will charge from the movement and will carry a charge until it is in contact with something and discharges. Dissipative and conductive footwear provide a channel from human body to the ground, preventing a charge to accumulate in human body. A dissipative or conducting floor is needed. This increases ESD safety when working with sensitive electronics. There are also anti-static heel straps that provide same channel from human body to the ground. Before entering an EPA it should be wise to check that footwear or the heel straps are conducting. Companies usually have ESD test stations for this, see figure 4. ESD test station has a conductive metal plate, which is insulated from the floor, a wire to connect the plate to a reference point and then a test device, also connected to the reference point, which has a test button and proper display that shows if footwear or heel strap is working properly. Setting a foot on the test plate and pressing the button will tell if you are not insulated from the ground. There are indicators on the test panel which will tell you if you have passed or failed the test by lighting up corresponding LEDs. ESD footwear is one of the key elements to prevent ESD damage, as seen in table 1. A person will be constantly discharging, preventing any substantial charges to buildup. As with any other protective gear, it is important to keep the footwear intact and clean. Broken shoe sole or them being covered in dirt increases the chance for not working properly. [2], [4].

Figure 4. ESD test station. [14]

Anti-static wrist straps are wearable grounding devices. It grounds a person to the common ground inside an EPA or to an anti-static mat in other cases. Anti-static wrist strap provides protection against accumulating charges and prevent ESD events. These are used when working with highly sensitive electronics. Wrist straps are made out of an elastic material that has conductive fibers in it and a coiled wire with a connector to the ground, socket or a crocodile clip. For extra safety some wrist straps have a 1 mega ohm resistor in the connection between the wire and the wrist strap. This protects from shock hazards when working with low-voltage devices. When working with higher voltages extra resistance is needed to provide safety against excessive currents. Normally every 250 V 0.75 mega ohms are added between the wrist strap and the ground. Wrist straps are fragile and have several failure mechanisms making them not that profitable protection method. A daily testing with a specific tester or a continuous monitor is needed. Also they can be clumsy, because they will eventually be in your way when working. Of course it is recommended to wear this in your non dominant hand. [2], [4].

ESD protective clothing is only considered in ESD protective areas, as cleanrooms. Different clothing materials can generate static charges on themselves. These charges as any other charges can discharge into a device under maintenance or have a strong enough electrostatic field that can induce charges. Synthetic fabrics, wool and silk are such clothing materials and need to be avoided when working with electronics. Cotton is a neutral material according to triboelectric series, see figure 2, and therefore is recommended clothing material to be used at normal worksite. Especially in an electrical repair workshop some devices that needs to be repaired can be covered by different impurities, gloves might be used. These gloves should be made out of dissipative or conductive material to prevent ESD events. Cleanrooms are used in different manufacturing processes that need certain precautions, but cleanrooms are not relevant in this report. All impurities can carry a charge so it is advisable to keep the clothing clean. [2], [4].

Anti-static mats are part of ESD protective gear that is widely used in different cases. Anti-static mat has a low electrical resistance to neutralize static electricity. The electrical resistance variates from 100 kilo ohms to 100 mega ohms, depending on the manufacturer. These anti-static mats are made out of at least two different layers of different material compounds. More information about the different ESD mat and floor material types are talked about in the next chapter. The bottom layer is conductive allowing fast discharge path to ground and to top layer is a static dissipative. These anti-static mats are provided for floor and table use. The mats also have a grounding socket that can be connected to a common ground or a wrist strap. Anti-static mats are good in field work, it’s an essential part of a temporary EPA. [2], [4], [6].

Having an ESD protective gear is not alone guarantee for ESD safe working. These materials are advisable to keep clean and intact. Chance for an ESD event increases with carelessness. A shoe covered in dirt or a mat with layer of dust can work as a catalyst for an ESD damage incident. [2], [4].

3.3 ESD Protective Floors

Proper flooring material with accompany of ESD protective footwear is the best way of controlling static charges. ESD protective floor is made in layers. At the bottom there is concrete subfloor, on top of that conductive adhesive to connect the wanted flooring material to the ground. Also from this layer there is a copper plate to common ground. On top of the adhesive layer will be added the wanted conductive or dissipative flooring material. Now there is a path through conductive footwear and the floor, for a static charge to be safely drained to the common ground. Choosing the correct floor type for an electrical repair workshop can be a time consuming matter. There are four types of different flooring materials being, rubber, vinyl, conductive wax, used as a surface treatment, carpet and epoxy. Each material have their ups and downs and it is important to understand what is needed at the worksite. Flooring can be either conductive or dissipative material, but it needs to follow ANSI/ESD 20.20 standard's requirements such as human body's, floor's and ESD protective footwear's combined resistance is below 35 mega ohms and human body cannot charge to over 100 volts potential. [4].

Rubber used as ESD protective flooring material works in many different purposes. There are dissipative and conductive rubber flooring materials. Electrically conductive rubber has been made using carbon. Carbon has really low electrical resistance and is highly conductive and everlasting material, extending the lifecycle of this flooring material to maximum. This material is also highly durable and is suitable for carrying heavy loads. When choosing the correct flooring material in a place where heavy electrical equipment is constantly moved around, a lasting material is needed. Rubber is also easy to clean and maintenance. Rubber will keep its electrical properties and there is no need to apply any conductive wax in its lifecycle. First thing that might come in mind from rubber is something soft, but in this case carbon infused rubber floor is not as porous as vinyl. Rubber flooring has high initial cost and low to moderate maintenance costs, depending which manufacturer's material is being used. [6], [7].

Vinyl comes usually in tiles or sheets. There are two type of vinyl materials, one that does not need conductive wax to maintain its ESD properties, and one that requires wax. Vinyl as a material is inexpensive, repaired easily, cheap and is durable enough to carry some heavy loads. Just a side note, vinyl can be quite spongy, and when moving heavy objects on small tires, carefulness is needed. When moving a tall object that has center of gravity relatively high, a porous floor can suck a tire in and the movement can suddenly stop. This can be dangerous and is good to keep in mind when moving anything across vinyl floor. Also constant moving of heavy objects can wear out the vinyl tiles rather fast. Vinyl tiles that need a periodic waxing is called vinyl composition tiles, and these are the most inexpensive ESD protective flooring material. Main downside on these are the wax, you need to be sure that the floor is intact and that the wax has not worn out. Because of this it has high maintenance cost and is not recommended to be used in long lasting solutions. Overall vinyl is not that good choice of a flooring material as a long term solution in a place where heavy products are constantly being moved around. But when simple ESD protection is needed vinyl can provide cheaply the sufficient ESD protective characteristics that are needed. A material that works with surface treatment has a low initial cost but the maintenance costs can be high. [6], [7].

ESD carpets come in anti-static, dissipative and conductive materials. These carpets have conductive fibres and anti-static additives inside them to neutralize static charges from generating. A soft texture is better to walk on and can work as a noise dampening material, which increases working comfort. These are not suitable for areas where heavy objects are being moved. Carpets are sold in tiles or as a fitted carpet for the floor. Carpets are easy to install and can be installed on almost any subfloor types that are at least electrically dissipative. They are easy to repair just replace the old fabric with new and maintenance is usually just vacuuming. Carpets are not meant for industrial use, but they can work fine in offices where ESD protection is also needed. [6], [7].

Epoxy is probably the most commonly used ESD protective flooring material in industrial use. Epoxy is made out of conductive or static dissipative grades of resin in a mixture of a proper hardener. Epoxy floor is made in several layers and in between these layers there are copper grounding wires to provide a path to the common ground. Epoxy can be altered with the mixture of different resins and hardeners. Carbon powder can also be added to the mixture to increase its conductivity. Alteration of an epoxy mixture provides a proper flooring for many different applications. A basic concrete floor can be covered with layers of epoxy resin. Epoxy provides great durability and is easy to install and maintenance. Durability ensures that constant movement of heavy objects will not break the floor. On the other hand epoxy being extremely hard material, it can be easily scratched and hard to repair. [6], [7].

3.4 ESD Handling

Knowing how to handle ESD sensitive materials is important. Whenever you enter an EPA you should be wearing proper garment and have needed knowledge how to work inside an EPA. When handling ESD sensitive materials whether you are working on installation or packing them, ESD safety is an issue of matter. Once ESDS leaves EPA it should be packed inside an antistatic bag or dissipative antistatic bag. All trained personnel are allowed to handle ESD sensitive materials. Training usually includes general information about electrostatic charges and discharges. [2], [4].

There are two different symbols to identify if the products are either sensitive to ESD or having an ESD control properties. Products that are marked by ESD susceptibily symbol are being handled inside EPA and should not be taken out of there unless packed. Products that are marked with an ESD protective symbol are used to control ESD events. These are all the materials talked earlier. These two symbols are pretty much look a likes, so it is important to recognize which one is which, see figure 4 below. [2], [4].

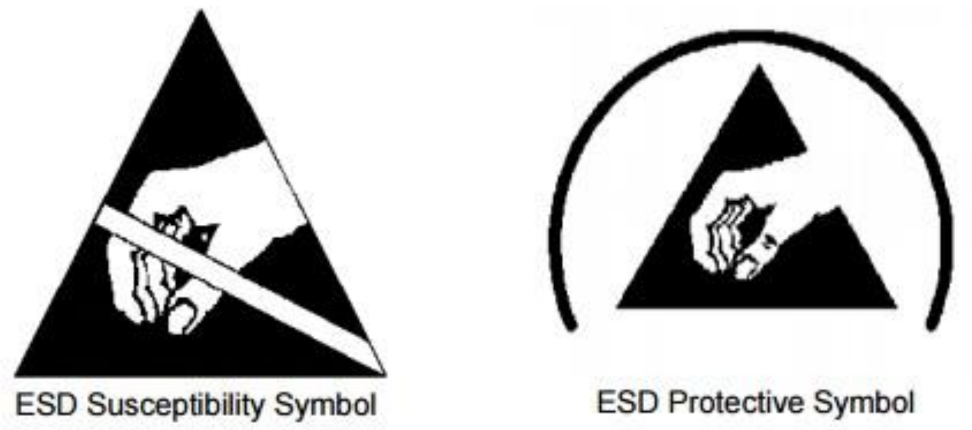

Figure 4. ESD Susceptibility Symbol & ESD Protective Symbol [11]

Handling ESDS are done inside an EPA. Only personnel with proper training are allowed inside the EPA or if anyone is to visit the EPA they need to be escorted with a trained person. Inside the EPA all conductors including working personnel needs to be grounded to the common ground. When using ESD footwear, you should test them daily. Keep work area clean and have all the unnecessary insulators away from the area. When storing or transporting use needed packaging material. [2], [4].

3.5 ESD Measurements and Testing Methods

When deciding how much of an ESD control is needed different ESD testing methods come in handy. As mentioned shortly before there are HBM, MM and CDM. First of all the correct testing method must be chosen, the possible ESD event must be taken under consideration. Is it going to be a discharge from a human, an automated machine/tool or an automated manufacturing line. [2], [4], [5].

The HBM testing method is the most common one out of these. It simulates an ESD from a human onto an electronic device. This is the most common case of ESD damage at electrical repair workshop. Usual damage that this ESD event makes is metal penetration, junction damage, melting metal layers and gate-oxide damage. The set up for this testing method is a simple circuit with a high-voltage power supply in series with a 1 Mohm resistor and a 100 pF capacitor, a switch and another loop with a 1.5 kohm resistor and the device under test (DUT). See figure of the circuit below, figure 5. The testing circuit works by first having a closed circuit on the power supply side, charging the capacitor. Once the capacitor is fully charged the switch is used to remove the capacitor from the power supply and discharging to the other loop. The charged voltage fully dissipates through the 1.5 kohm resistor and the DUT. The range of voltage values used varies between 0.1 to 15 kV. The voltage determines what level of susceptibility the DUT has. Table below shows the classification voltage range, see table 2. [2], [4], [5].

Table 2. HBM ESDS Component Classification Voltage Range (V) [4]

0A	< 125
0B	125 to <250
1A	250 to <500
1B	500 to <1000
1C	1000 to <2000
2	2000 to <4000
3A	4000 to <8000
3B	≥8000

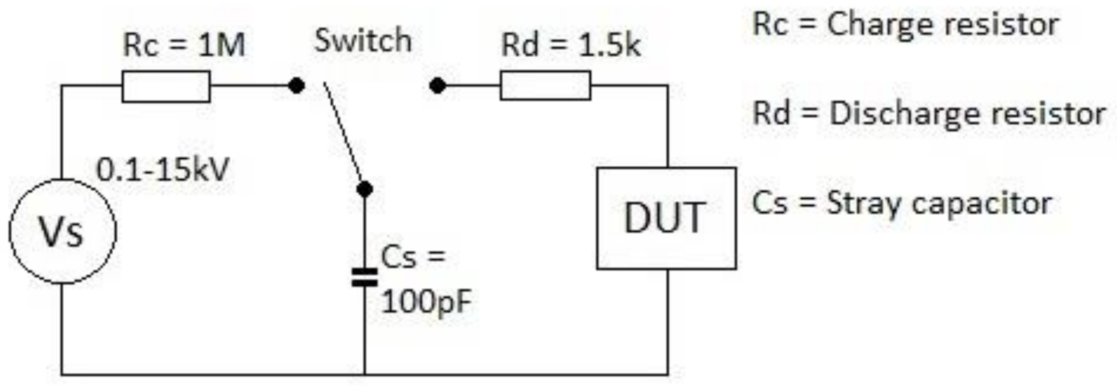

Figure 5. HBM testing circuit. Modified from [5].

The MM testing method was popular when automation manufacturing sites became more popular. Automated machines can come charged after the power is set on. Therefore up on contact the machine would discharge to object under construction. Even though the ESD event is little bit different from HBM the failure modes are about the same. The testing circuit is very similar to the HBM one, as seen in figure 6. There is a high-voltage power supply in series with a 1 Mohm resistor and 200 pF capacitor, switch and another loop with a 0.5 uH inductor and the DUT. You charge the capacitor once again flip the switch and then the set voltage dissipates through the DUT. This test is done usually with a voltage range of 50 to 400 V, see table 3 below for component classification limits. Some high-voltage applications can be done as well. [2], [4], [5].

Table 3. MM ESDS Component Classification Voltage Range (V) [4]

M1	<100
M2	100 to <200
M3	200 to <400
M4	≥400

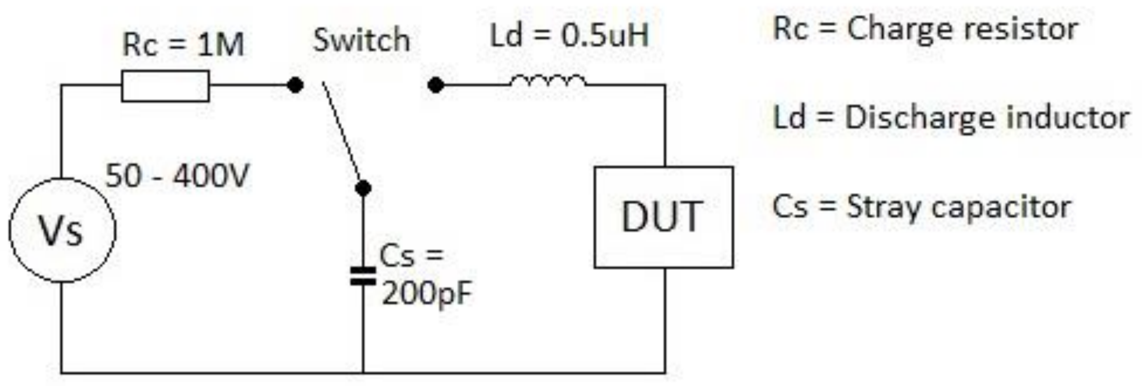

Figure 6. MM testing circuit. Modified from [5].

The CDM testing method is considered useful when using automated manufacturing lines. The charge will build up to the device and will damage it when discharging into a grounded conductor. The setup for this testing method is little bit more complex than the previous two. DUT is placed on a metal ground plate, and these two are separated with and insulating material, making it act like a capacitor. This way the DUT can charge up. The metal plate is then connected to a high-voltage power source in series with a larger than 10 Mohm resistor. You test it by charging the plate with wanted voltage though the power source and then discharging it. A table of classification voltage limits is described below, table 4. Also a model of CDM testing circuit below the table, see figure 7. [2], [4], [5].

Table 4. CDM ESDS Component Classification Voltage Range (V) [4]

C1	<150
C2	150 to <250
C3	250 to <500
C4	500 to <1000
C5	1000 to <1500
C6	1500 to <2000
C7	≥2000

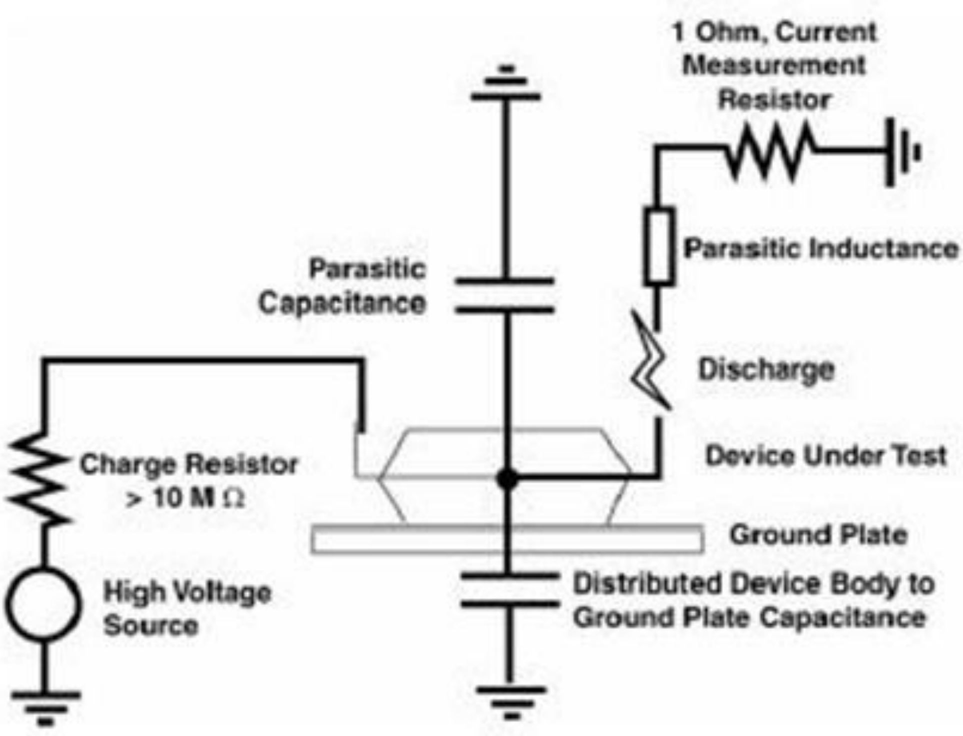

Figure 7. CDM testing circuit. [5].

These three testing methods are the most common ones used. They help you to figure out which type of ESD event you are facing and what level of protection is required. The limits are not guaranteed, but they give and idea how much the DUT can with stand until failure. [2], [4], [5].

3.6 ESD Training and Auditing

Every electrical repair workshop needs to give their personnel a proper ESD training. By this training personnel will know how to work on ESDS. Basic training includes the basic concept of ESD events, ESD effects on an ESDS, how to handle ESDS, usage of ESD control garments and equipment, and working methods inside an EPA. This material covers all of these fields and could be used for training. Importance of training relies heavily to cut the unnecessary expenses. As mentioned before ESD damage can cut profitability and reliability. In a constantly developing field such as electronics the competition is tough. If products from one company are not as reliable as in another one, customers will use the more reliable one. So it is important that whoever is working on ESDS knows what they are doing. [2], [4].

After personnel has been trained, occasional audits can be done to proof that the ESD control does its job and the personnel keep working by the rules. These auditions are done by checking the working areas, condition and proper usage of ESD control equipment and garment, there are no unnecessary insulators inside an EPA, ESDS are packed and labelled correctly, discharge devices are wired to the ground, ESD protective floor is clean, intact and connected to the common ground, EPA is marked properly and there are no unauthorized personnel there, and that the ESD maintenance schedule is maintained. These audits are also made when a new repair workshop is opened or when making a contract with a new customer. In that case the audit is held by the customer's representative and escorted inside the workshop with authorized personnel. [4].

4 EPA

ESD protected area is where all the ESDS are being worked on. This area is essential for ESD safe environment. EPA can be a simple workstation with an ESD safe desk, tools, and ESD control equipment. When setting up an EPA there is no idea going all in ESD control. By recognizing how much of ESD control is needed, a significant amount of money can be saved. Main feature of an EPA is an environment where ESD events should not occur and in case of an ESD event it will safely dissipate without doing any damage to sensitive devices. [4].

4.1 Setting up an EPA

When setting up an EPA everything that were discussed in Chapter 3. ESD protection, can be implemented. First of all flooring options need to be considered. Choosing the correct flooring option for your need is important, are heavy objects going to be moved across the floor or is a cheap PVC vinyl going to be enough. After building the floor you start by defining what areas are going to be EPA and which are not. All areas that are used to work on ESDS should be marked with EPA signs and floor tape to show the boundaries for authorized and unauthorized personnel. Inside EPA there should not be any materials that work as an insulator. Insulators increase chance for an ESD event to occur. For visitors, outside an EPA should be disposable ESD heel grounders and a test unit to check that your shoes are conducting. At the workstation there should be an ESD safe workbench that is connected to the common ground via 1 Mohm resistor. ESD wrist bands are recommended, but not always needed. With a proper flooring option and conductive shoes, human body will not charge high enough to do damage. There are exceptions depending on the level of ESD control. Workstation includes ESD safe chair, workbench, tools and containers. If ESDS are being transported outside of EPA or stored, the packing material is necessary. Packing material is also stored inside EPA. Trolley's that are used to move ESDS inside EPA needs to be ESD safe as well. Storage area and storage selves need to made ESD safe. EPA is necessary to keep clean and maintenance regularly. Impurities on surfaces can carry a lethal charge for an ESDS. For cleaning use only cleaning supplies that are meant for ESD materials. Personnel working inside an EPA are equipped with proper ESD control garments. [4].

4.2 Temporary EPA

When working out in the field, setting up a temporary EPA is usually needed. Equipment's to build a simple yet effective EPA can be carried along. ESD mat, conductive shoes or heel grounders, wrist band that can be connected to the mat and proper tools are needed. Up on arrival to worksite, define the perimeters for needed space and close to the device you are working on. All unnecessary movement and transportation is clever to cut out and minimize the risk of an ESD event. Lay down the ESD mat and connect your wristband to it. Now you and the ESD mat share the same potential. Make sure that the ESD mat is intact to ensure it works properly. On this mat it is safe work on ESDS. Just make sure you are standing on the mat and not on the floor, it might not be dissipative. After repair work is done, move the repaired device back to its place with caution to prevent any damage. [2], [4].

5 Discussion

What can be learned about ESD safety through this thesis, is that there are a lot of different ways to prevent ESD events from occurring. Controlling ESD is also really important for companies to make their product lines and repairs as profitable as possible. ESD control is a huge market with a lot of unnecessary and necessary stuff. Without a general knowledge on ESD, companies can overextend their safety to way beyond and spend significant amounts of money for basically nothing. Doing the research can take a while but will cut the budget for you. Static electricity is a common phenomenon that happens constantly around us. A discharge from a tip of your finger that you cannot notice can damage a sensitive component so that it will be either broken or defected, and break down prematurely. There are definitely people doing research to improve the testing methods and how to spot the currently unnoticeable defects. And as the technology advances, integrated circuits are getting smaller and more complex causes them to be more sensitive for external factors such as ESD. While technology improves, the materials used or circuits that are made should be done less susceptible to these external factors. But in overall ESD control is used widely in all different field and it is good to know how easily static electricity builds up and what the discharge can do.

6 Conclusion

ESD is a common problem in the field of technology and the main goal of this thesis was to find out how to protect from ESD events. The way to approach these problems were doing research on different sources. Going through different material online and as books gave better idea on the whole subject. Due to the amount of problems that a simple ESD shock can do, ESD safety and control is important. There are several different ways to control ESD, not every single one of them needs to be used. It is important to recognize what level of ESD control is needed. Workstation also known as EPA needs to be clean and there should not be any materials that are insulative. Dissipative and conductive materials provide a safe way for the accumulated charge to be transferred away. Insulators does not dissipate and can carry a charge that will harm your ESDS. Basically with a proper dissipative floor, conductive ESD shoes and training, you can limit almost all damage occurred from a human body. The goal was reached by finding out enough information for how to work with ESDS and proper instructions were made.

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