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Compliance is Mandatory

ELECTROSTATIC DISCHARGE CONTROL REQUIREMENTS FOR THE PROTECTION OF ELECTRONIC COMPONENTS AND ASSEMBLIES

Responsible Office:
Engineering Directorate

ELECTROSTATIC DISCHARGE CONTROL REQUIREMENTS FOR THE PROTECTION OF ELECTRONIC COMPONENTS AND ASSEMBLIES

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Change History Log

Revision	Date	Originator	Description of Changes
Baseline	March	Stephen Trifilo	Initial Release (was formerly JPR 8730.1)

1.0 SCOPE

This document defines the process, roles, responsibilities, and technical requirements for ESD control. Based on the requirements and guidelines found in this document, the responsible party for each facility or laboratory shall identify each ESD control work area. The responsible parties shall then develop an ESD Control Plan for each work area. This document provides guidance on how to comply with NASA Policy Directive 8730.5 (NPD-8730.5) that imposes ESD standard ANSI/ESD S20.20-2007.

1.1 Purpose

The purpose of this document is to establish the standards for an Electrostatic Discharge (ESD) control program designed to protect Electrostatic Discharge Sensitive (ESDS) components, sub-assemblies, and assemblies that are susceptible to ESD damage at voltage levels equal to or above 250 volts. For handling ultra-sensitive devices that can be damaged at voltage levels below 250 volts, Table 5-2 ESD Requirements for Workstations Handling ESD Sensitive Components, Class 1 and Table 6.1-1 ESD Certification and Periodic Inspection requirements become mandatory.

1.2 Applicability

This document is applicable to any Johnson Space Center (JSC) organizational element or contractor facility that:

1. Handles ESDS space flight components for storage, test, evaluation, or analysis of these components; and /or
2. Performs construction, test, repair, rework, or modification of any electrical or electronic Line Replaceable Unit (LRU), module, assembly, or sub-assembly that contains or may contain ESDS sensitive components.

The standards defined in this document are applicable to all JSC organizations and contractors, both on-site and off-site that handle flight hardware and components or mission-essential ground support equipment. For the purposes of this document, the following definitions are used:

Flight hardware includes spacecraft, launch vehicles, payloads, experiments, and any element of these components where invoked contractually in procurements.

Mission-essential ground support equipment may include ground data processing hardware, unique payload support hardware for installation and functional checkout, and related equipment.

This document does not include controls for pyrotechnics, flammables, or explosives.

Measures for controlling electrostatic discharge shall be implemented during all phases of hardware handling including the receiving, inspection, assembly, testing, modification, repair, storage, and shipping of all items designated as ESDS. ESD sensitive items that are properly protected as described in this document do not require special precautions, such as use of a wrist strap, when they are being handled.

Facilities that handle ESDS hardware at the orbital replacement unit (ORU) level exclusively shall comply with Table 5.4-1 ESD Requirements for Workstations Handling ESD Sensitive Components, Class 3 requirements.

1.3 Conventions

Requirements are indicated by the word "shall".

1.4 Measurement / Verification

Verification of the requirements contained within this standard is primarily accomplished through the identification, inspection and certification of JSC facilities handling Electrostatic Discharge Sensitive material. These inspections are performed to the requirements contained in this document.

1.5 Cancellation / Rescission

Upon issuance of this standard, the following documents are cancelled:

Doc. No.	Rev.	Document Title
JPR 8730.1		Electrostatic Discharge Control Requirements for the Protection of Electronic Components and Assemblies (April 2008).

2.0 REFERENCES

The latest issuances of cited documents shall apply unless specific versions are designated.

2.1 Applicable Docs

The documents listed in this section contain provisions that constitute requirements of this standard as cited in the text.

Doc. No.	Document Title
ANSI/ESD S20.20-2007	Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
ANSI C63.16-1993	American National Standard Guide for Electrostatic Discharge Test Methodologies and Criteria for Electronic Equipment
ESD TR20.20-2008	Handbook for the development of an Electrostatic Discharge Control Program for the Protection of Electronic Parts, Assemblies and Equipment
IEC 61000-4-2	Electromagnetic Compatibility (EMC) – Part 4.2: Testing and Measurement Techniques – Electrostatic Discharge Immunity Test
IEEE STD C62.38-1994	IEEE Guide on Electrostatic Discharge (ESD): ESD Withstand Capability Evaluation Methods (for Electronic Equipment Subassemblies)
MIL-STD-129P	Change 3, Marking for Shipment and Storage
MIL-STD-1686C	Protection of Electrical and Electronic Parts, Electrostatic Discharge Control Program for Assemblies and Equipment (Excluding Electrically

	Initiated Explosive Devices)
MIL-E-17555	Packaging of Electronic and Electrical Equipment, Accessories, and Provisioned Items
MIL-PRF-19500	Semiconductor Devices, General Specification for
MIL-PRF-38510	Performance Specification, General Specification for Integrated Circuits Manufacturing

2.2 Resolving Conflicts

In the event of a conflict between this standard and nay applicable or reference documents, this standard takes precedence. In the event of a conflict between this standard and a NASA Policy Directive (NPD) the NPD takes precedence.

2.3 Reference Docs

Additional informative references are located in Appendix C.

3.0 ACRONYMS, TERMS, AND DEFINITIONS

Specialized terms, acronyms, and definitions used in this document are defined in Section 3.0.

4.0 RESPONSIBILITY

4.1 Safety and Mission Assurance

The JSC Safety and Mission Assurance (S&MA) Office shall be responsible for identification, inspection, and certification of JSC facilities handling Electrostatic Discharge Sensitive (ESDS) materials. S&MA shall monitor conformance to the requirements of this document via the work area Electrostatic Discharge (ESD) Control Plan for all locations handling ESDS parts and assemblies. These control measures shall be implemented during all phases of design, procurement, assembly, disassembly, troubleshooting, testing, maintenance, modification, handling, inspections, storage, shipping, and receiving.

4.2 ESD Testing and Verification Officer

An ESD Testing and Verification (ET&V) Officer who is an ESD Association Certified Engineer or Inspector shall lead the S&MA function for identification, inspection, and certification of JSC facilities handling Electrostatic Discharge Sensitive (ESDS) materials.

All ESD Testing and Verification (ET&V) employees shall be formally trained by attending one or more sessions of training offered by the ESD Association.

> Rationale: The requirements for this section derive from ESD TR20.20-2008, Section 4.3 – Developing a Compliance Verification Plan. Refer to that source for further information.

4.3 JSC Labs and Facilities

The ET&V Officer shall ensure the following tasks are performed:

Identification of all JSC labs and facilities handling ESD sensitive items.

Initial audit/certification and recertification of all JSC labs and facilities handling ESD sensitive items.

Qualification and periodic verification testing of ESD protective materials.

Periodic re-inspection of all certified labs.

Conformance and compliance audits of labs and facilities using a JSC approved alternative ESD Control Requirement. Compliance audits may be performed by the contractor. An independent certified third party may perform compliance audits when this requirement is imposed by the procurement contract and/or engineering documentation and when this arrangement has been approved by the JSC ET&V Officer.

4.4 Contractor Labs and Facilities

Inspection and certification of contractor ESD-protected labs and facilities shall be performed. This audit may be performed by either the contractor or the ET&V officer, depending on prior agreement. An independent certified third party may inspect and certify contractor ESD-protected labs and facilities when this requirement is imposed by the procurement contract and/or engineering documentation and when this arrangement has been approved by the JSC ET&V Officer.

The contractor or independent certified third party shall maintain records of inspections, certifications, and compliance audits performed by the contractor or independent certified third party. These records shall be available to the ET&V Officer upon request and delivered to NASA/JSC as part of the procurement.

Periodic verification of compliance shall be at the discretion of the JSC S&MA.

4.5 Design Engineering

The organization performing the design engineering function shall select components that provide the greatest immunity from ESD damage consistent with the performance requirements of the design. The design engineering organization shall ensure that all drawings document ESDS components as detailed in Section 7.1 of this standard.

4.6 JSC Support for ESD Issues

JSC Avionics Systems Division (EV), JSC Safety and Mission Assurance (NT), and the ET&V Officer shall assist NASA JSC and contractor organizations in determining ESD sensitivity of a device or hardware interface. They will also help in determining ESD protective equipment requirements and facility ESD test planning. Additionally, these groups will provide technical expertise for ESD related problems and questions.

5.0 TOOLS AND TASKS REQUIRED TO MAINTAIN AN ESD CONTROL PROGRAM

5.1 Training

The S&MA Directorate shall provide ESD training for required NASA and contractor personnel. Personnel subject to training shall include, but are not limited to, those personnel listed in Table 5.1-1 ESD Training Guidelines. All contractor training courses and instructors shall be approved by S&MA and EV and conform to the requirements of this document.

ESD training shall be oriented to the functional needs of the personnel being trained. Table 5.1-1 outlines the ESD training needs for various job functions. Temporary or transient personnel who have not been trained and who enter an ESD protected area:

shall conform to the local protective equipment requirements when entering a controlled work area;

shall be briefed on ESD precautions for the area;

shall maintain a 1-meter minimum distance from ESDS items unless wearing a grounded wrist strap and accompanied by an ESD certified attendant.

Table 5.1-1 ESD Training Guidelines

LEVEL	TYPE OF PERSONNEL	FREQUENCY	TRAINING COURSE OUTLINE
1	Program Managers Purchasing Personnel Janitorial Personnel	Once	A general ESD overview class with specifics about the particular issues associated with the trainees' job function and ESD protection of hardware.
2	Engineering Personnel Quality Assurance Personnel Field Engineer and Maintenance Production Operators and Assemblers Material Handlers and Stockroom Personnel Test Personnel Inspection Personnel	Every 24 Months	Training must cover all aspects of ESD protection of sensitive parts and hardware.
3	Personnel responsible for a facility ESD control plan and internal auditing of the facility (Facility ESD Monitors).	Every 5 years	Hands-on training in the use of inspection equipment required to perform a facility ESD audit, sufficient knowledge to write a facility ESD control plan and perform the tasks of a Facility ESD Monitor. Prerequisite: Level 2 Certification must be repeated every 2 years.

Rationale: This requirement derives from ESD TR20.20-2008, Section 4.2 – Developing a Training Plan. Refer to that source for further information.

5.2 Personnel Certification

S&MA shall provide ESD training and periodic re-certification to all required personnel as defined in Table 5.1-1 of this document. As a minimum, all ESD training courses used for certification shall, be approved by EV and NT. The S&MA Directorate has the authority to certify personnel for handling ESDS hardware and components. This authority may be delegated to another NASA organization or contractor who has been approved to perform certification.

Upon completion of training, all personnel shall take a written test on the applicable training materials. Upon successful completion of ESD training, they shall be issued a “Certificate of Completion” that lists the training modules completed, expiration date of certification, and each individual’s organization name.

Each organization shall maintain a record of all ESD certified operators assigned to them and ensure that these certified operators are notified when retraining is due. The Facility ESD Monitor shall maintain a record of the ESD training status for all employees working in each location and have it readily available.

5.3 Re-Certification

S&MA shall provide periodic re-certification to all personnel certified at course levels 2 and 3 of Table 5.1-1. All personnel involved in the direct assembly, disassembly, inspection, testing, handling, training, or storage of ESDS items shall be required to be re-certified every 24 months. The procedure for re-certification shall include sufficient training or retraining to enable the candidate to demonstrate proficiency in protecting ESDS items. Certified S&MA personnel will periodically verify all ESD certification and re-certification testing content.

5.4 Class 1, 2, and 3 Facility EPA Certification

(Reference ESD TR20.20-2008, Section 4.3 – Developing a Compliance Verification Plan)

An auditor from the ET&V Office or designated representative shall perform initial certification of each JSC Electrostatic Protected Area (EPA) and the Compliance Verification Plan for that area.

The three classes of certification for an EPA are:

Class 1: A class 1 work area has the highest level of certification and will allow handling of all ESDS items.

Class 2: A Class 2 work area provides protection to devices and hardware that will not be damaged by a voltage level below 250 volts.

Class 3: Class 3 certification is for work areas that only handle items at the LRU level with no exposed ESD sensitive parts other than connector pins and sockets during inspection and/or the cable mate and demote process. Hardware with exposed connector pins or sockets not certified to prevent hardware damage when exposed to a voltage below 1,999 volts shall not be handled in a Class 3 facility.

An EPA certification report shall address compliance to Table 5.4-1 ESD Requirements for Workstations Handling ESD Sensitive Components, and shall include the following:

Level of certification (Class 1, 2 or 3),

Date of the audit,

Names of the personnel performing the audit,

Specific ESD requirements audited,

Documented results of the audit and any corrective actions taken and completed.

The ET&V Officer shall grant EPA certification in writing and shall maintain records of all audits performed. The responsible party for each EPA shall have on file the findings from the periodic verification audits performed by the Facility ESD Monitor referenced in Table 6.1-1 ESD Certification and Periodic Inspection. Recertification of all work areas:

shall be done by the ET&V Officer upon request by the lab owner or S&MA or

shall be done within 5 years from the last facility certification

The following table is a summary of the applicable requirements for Class 1, 2, or 3 workstations that handle ESD sensitive components. In this table, “M” signifies that the equipment is mandatory, and “O” signifies that the equipment is optional.

Table 5.4-1 ESD Requirements for Workstations Handling ESD Sensitive Components

STANDARD Section	Subject	Class 1	Class 2	Class 3
3.2	Identification and Access	M	M	M
3.3	Storage and Locker Facilities	M	M	O
3.4	Prohibited Activities and Items	M	M	O
3.5	ESD Protective Work Surface	M	M	M
3.6	ESD-Protective Floors Mats and Conductive Floors	M	O	O
3.7.1	Wrist Straps	M	M	M
3.7.2	Leg Straps, Heel Straps, and Conductive Shoes	O	O	O
3.8	Equipment and Facilities Grounding	M	M	M
3.8.1	Stool and Chairs	M	O	O
3.9	Relative Humidity Control	M	M	O
3.10	Air Ionizers	M	M	O
3.11	Hand Tools, Equipment and Fixtures	M	M	O
3.12	ESD Protective Packaging	M	M	M
3.13	Grounded Carts, Wagons, and Trams	M	M	M
3.14	Temperature Chambers and Cooling Agents	M	M	M
3.15	Cleaning ESDP Areas	M	M	M
3.17	Electrostatic Detectors, Monitors and Voltmeters	M	M	O
3.18	Contamination Control	M	M	M
3.19	Clothing Requirements	M	M	O
4.1	Drawing Requirements and Identifications of ESDS Items	M	M	O
4.4	Packaging Identification of ESDS Items	M	M	M
4.5	Shipping and Receiving	M	M	M
4.5	User Receiving Inspection	M	M	M
4.7	Packaging and Shipment of ESDS Items	M	M	M
4.8	Printed Circuit Board Level ESD Protection	M	M	N/A
4.9	Storage of ESDS Hardware	M	M	M
5.0	Orbital Replaceable Unit	M	M	M

O = Optional, M = Mandatory

5.5 Facility ESD Monitors

Each organization responsible for an Electrostatic Protected Area (EPA) shall assign a Facility ESD Monitor who will ensure that each EPA complies with this document and/or the JSC approved program documentation. The Facility ESD Monitor shall perform periodic inspections/tests set forth in Table 6.1-1 ESD Certification and Periodic Inspection, and agreed upon by the ET&V Officer as well as any inspection or test required by a manufacturer of an ESD-Protective item not covered in Table 6.1-1. The following records will be kept by the Facility ESD Monitor:

Documentation for the location, typical work performed, and facility classification of each EPA, Class 1, 2 or 3.

ESD-Protective (ESDP) equipment and materials used in the EPA along with proof of calibration and certification of consumables that contact ESDS hardware.

Date of the initial and periodic facility inspections.

Findings of the inspection/test and the action taken after the inspection/test.

A current listing of all ESD certified personnel, and their certificate expiration dates, who are assigned to the monitor's area of responsibility.

All ESDP items that fail the acceptance criteria shall be immediately removed from service and either refurbished or replaced. Any hardware that the failed ESDP items were used on must be evaluated for potential damage. The hardware owner, ET&V officer and Facility monitor shall determine what actions are required to assure the hardware has not been damaged. The ET&V Officer and/or S&MA personnel shall periodically monitor each EPA to ensure that ESD certification and periodic inspections have been performed as required by Table 6.1-1 and that assigned personnel are properly certified.

5.6 ESD Control Plan

The party responsible for each EPA shall develop an ESD Control Plan based on the requirements and references herein and ANSI ESD S20.20-2007. This EPA plan shall, as a minimum, address the tasks being performed, the work environment, and the ESD sensitivity of the most sensitive items handled, verification of training and processes, and the mission of the processed items.

ESD-control plans for each EPA shall be submitted to the JSC-EV and the JSC-NT group for technical evaluation. Approval shall be required from the ET&V Officer prior to handling or processing of ESDS flight hardware and components or mission-essential ground support equipment.

> Rationale: This requirement derives from ESD TR20.20-2008, Section 5 – ESD Control Program Plan – Technical Requirements. Refer to that source for further information.

5.7 Material Certification and Quality Inspection Requirements

All ESDP materials and equipment shall be properly certified for their intended uses. All materials and equipment require initial certification/inspection prior to use. Table 6.1-1 details the items that require periodic certification/inspection and the frequency of those inspections. Various sections of this document provide the test procedures and pass/fail criteria for certification. The JSC ET&V Officer will provide a list of approved and recommended sources for ESDP materials. If materials are selected from this approved list, they may not require initial certification. Certification exemption will be based on testing done by the manufacturer and/or NASA. Certification requirements for clean room usage and/or use aboard spacecraft will require more stringent testing than covered by this document.

All ESDP items and procedures are subject to quality control (QC) inspection at any time and shall meet their initial JSC certification requirements and the manufacturer's published requirements for each item. Materials not meeting these requirements shall be immediately removed from service and replaced with conforming materials and a determination made if the hardware was damaged.

> Rationale: This requirement derives from ESD TR20.20-2008, Section 2.6 – Material Test Principles. Refer to that source for further information.

5.7.1 Reusing ESD Protective Materials

Many ESDP packaging materials have a finite service life and shall be inspected prior to reuse for any visual and/or electrical indication of deterioration. Some materials, such as pink poly, have a limited shelf life after which they are no longer static dissipative and must be discarded. The manufacturer's recommended life span for the material should be used as a minimum requirement. If no manufacturer's recommendation can be found, the information provided in ANSI/ESD S541-2008, Table 3 should be used as a guideline for testing to verify that the material is still good.

The Facility ESD Monitor shall track limited life items within their area of concern and remove expired materials. Certain expired materials may be retested to have their shelf life extended. The ET&V Officer shall provide guidance on procedures for initial material certification and recertification.

5.8 ESD Equipment Control

Schedules for equipment calibration or setup shall be developed, documented, and referenced in the detailed operating procedures of each laboratory or facility. These schedules shall meet manufacturer's recommendations as a minimum. Facility ESD Monitors shall approve the calibration frequency of ESDP items within the work area under their responsibility. The Facility ESD Monitors shall maintain records of all ESD equipment calibration and verification. Equipment shall be tested using procedures specified by the ESD Association available at the Web site www.esda.org.

6.0 ESD CONTROL PROGRAM TECHNICAL REQUIREMENTS:

6.1 General

A vital principle of ESD control is that all conductors have a common bond or be electrically connected to “common point ground.” The following table calls out the principle items of concern that require periodic monitoring to ensure an ESD-safe work area. In addition to the requirements detailed in the applicable sections below, use the guidelines in ESD TR20.20-2008, section 5, to provide additional interpretation and insight into the test methods needed to perform the verification. Each facility shall develop a work instruction detailing their process for compliance to Table 6.1-1.

Table 6.1-1 ESD Certification and Periodic Inspection

Paragraph	Areas of Concern	Inspection Frequency				
		Each (1) Work Shift	Weekly	Monthly	Semi-Annually	Annually
3.5	Work Surface Resistance to Ground			X		
3.5	Work Surface Static Charge Dissipation					X
3.5	Work Surface Grounding		X(3)			
3.6	Conductive/Dissipative Floor Resistance					X (1)
3.7.1	Wrist Strap Resistance	X (3)				
3.7.2	Leg and Heel Strap & Shoe Continuity	X (2)				
3.8	Equipment & Facility Grounding				X	
3.8.1	Stools and Chairs				X	
3.9	Relative Humidity Control	X				
3.10	Air Ionizer Effectiveness					X
3.11.1	Soldering Iron Tip Grounding		X			
3.12	ESD Protective Materials & Packaging	X (4)				X (4)
3.13	Cart, Wagon, and Tram Grounding				X	
3.14	Temperature Chambers					X
3.15	Work Surface Solvent Resistance (certification only)					X
3.16	Electrostatic Monitoring System			X		
3.18	Garments				X	

Notes:
The test limits and procedures for testing the above materials are detailed in ANSI/ESD-S20.20, Table 1

1) Items requiring “each shift” verification must be tested only if the item is being used on the shift in question.
2) When conductive flooring and footwear are used in lieu of wristbands, resistance measurements shall be performed at the beginning of each work shift.
3) If a continual workstation-grounding monitor is used, only monthly verification that the monitor is working correctly is required.

4) ESD packaging materials shall be verified when received and periodically based on the manufacturer's estimated life cycle.

6.2 Identification and Access

The EPA shall be clearly identified by prominently placed signs. Access to such areas shall be limited to properly trained and suitably equipped personnel.

A test facility that installs and removes LRUs which are not ESDS, except through unprotected electronic connectors, is required to limit access to the work area only when an LRU has exposed connector pins.

Rationale: This requirement derives from ESD TR20.20-2008, Section 5.3.10 – Signs. Refer to that source for further information.

6.3 Storage and Locker Facilities

Adequate storage and locker facilities shall be provided outside of the EPA by the work area owners to prevent the introduction of uncontrolled static-producing materials and other personal items into the ESD safe area.

6.4 Prohibited Activities and Items

No untreated, charge-generating materials are allowed in an EPA. To prevent the introduction of static-generating substances such as Styrofoam® coffee cups, potato chip bags, candy wrappers, sandwich bags, and other cellophane wrappers into an EPA, all smoking, eating, and drinking shall be prohibited within an EPA. The ESDP workstation should be clean and free of all unnecessary items. Personal items, such as pictures, cards, papers, bags, plastics, money, keys, etc. shall not be placed on a manufacturing surface or the shelf above. Prohibited items shall not be placed within 36 inches of any ESDS component or hardware.

Televisions, computer CRTs, and other items can generate thousands of volts of an electric field that can easily be induced into ESDS items. Any devices producing an electric field 1000 V/inch or more shall remain 36 inches away from any ESDS item or protective work surface.

6.5 ESD Protective Work Surfaces

The ESDP work surface (Reference ESD TR20.20-2008, section 5.3.1 – Work surfaces) will provide a safe path to ground for static charges within the operator's general working area. Either the ESDP work surface may be fabricated as a part of the workbench or it may be a separate add-on item. In either case, the ESDP work surface shall be grounded and static dissipative with a resistance to ground measurement between $1x10^6$ to $1x10^9$ ohms. Applications where hard grounding of the LRU is required are excluded. ESD S4.1 "ESD Association Standard Method for the Protection of ESDS Items – Workstation – Resistive Characterization" describes the test methods for work surfaces. Grounding of the work surface may be accomplished with the use of a current limiting resistor that is generally a ¼ watt, 250V part. The maximum voltage rating of the resistor defines the maximum working voltage of the surface. The use of a series resistor is recommended for personnel safety if the currents from accessible voltages at the workstation could exceed 5mA through the static-dissipative protective work surface. For personnel safety, the use of a ground fault circuit interrupter (GFCI) is recommended in situations where personnel may come in contact with hazardous current levels.

The ET&V Officer shall check the work surface ground continuity during initial certification. Thereafter this check can be done by lab personnel on a weekly basis. It is strongly recommended that electronic monitors be used to monitor continuously the integrity of the work surface ground.

The manufacturer's recommended chemicals and methods that will not damage the work surface shall be used to clean the work surface as required.

Exposed metalwork surfaces are not acceptable for ESD workstations. If a special situation requires a conductive work surfaces, it must be hard grounded. If a painted metal bench is used, the metal must be covered with a static dissipative material. See Figure 6.5.1 and Figure 6.5.2 for examples of how a workstation should be connected to meet ESD requirements.

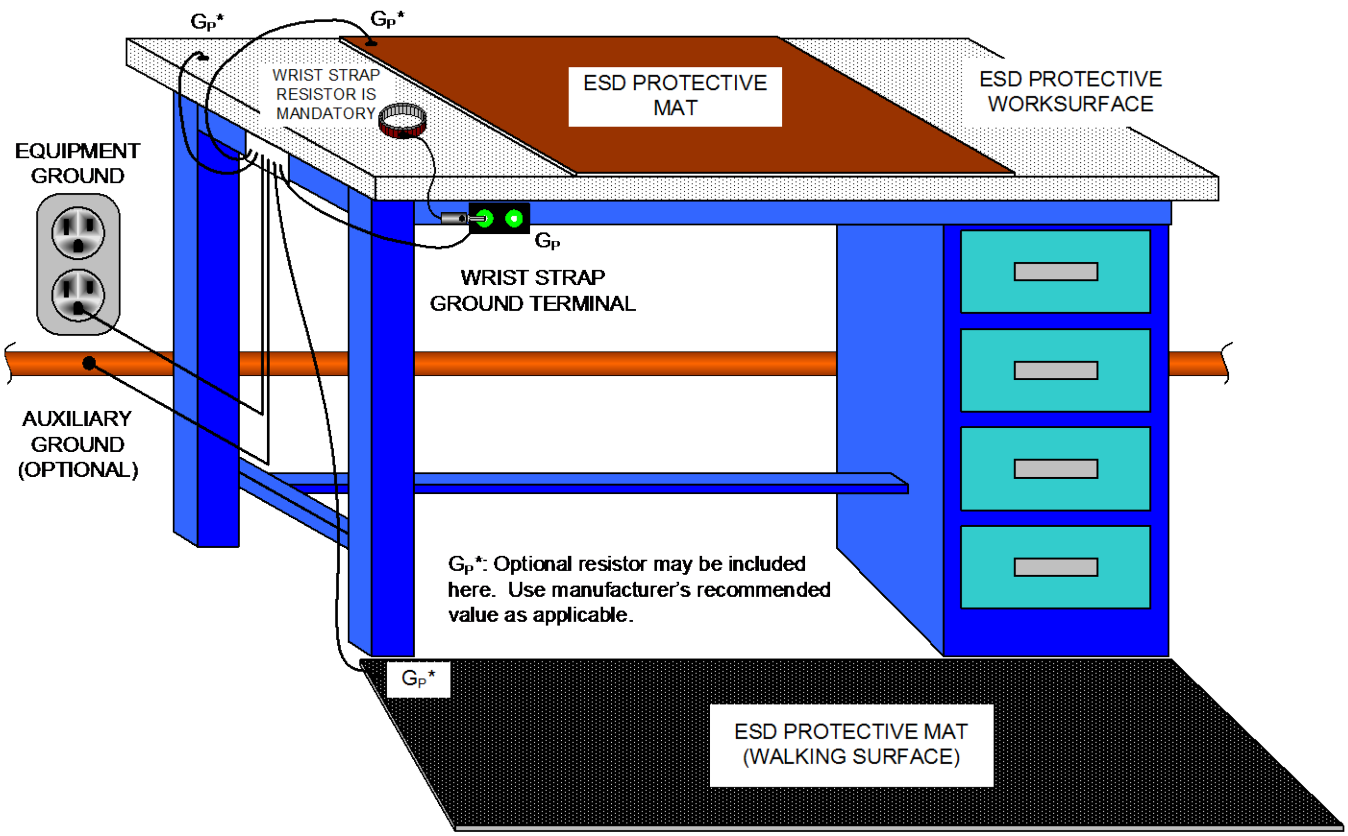

Figure 6.5.1 Typical ESD Protective Station Grounding Systems

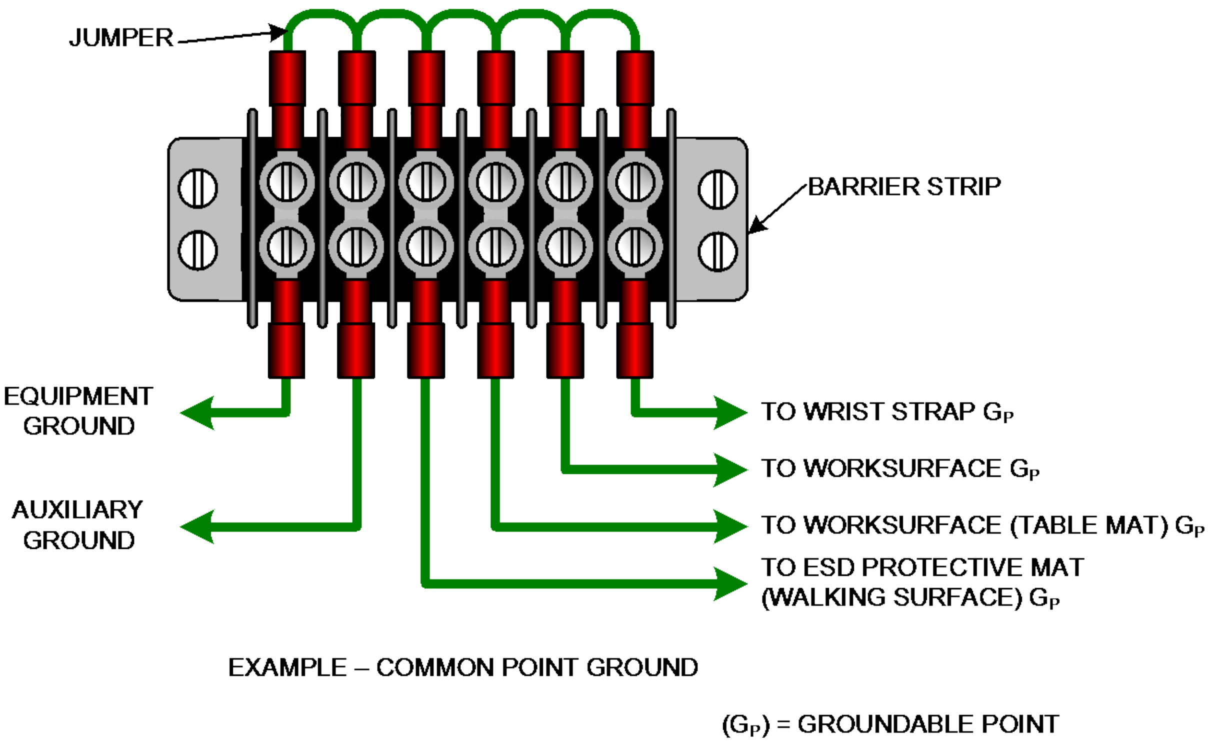

Figure 6.5.2 Typical Barrier Strip Common Ground Point

6.6 ESD Protective Floor Mats and Conductive Floors

Conductive floors or grounded conductive floor mats are mandatory in any EPA where personnel handling ESDS items are not wearing wrist straps. Under these circumstances, personnel shall use leg straps, heel straps, or conductive shoes.

ESDP flooring or floor mats shall be used in all Class 1 facilities.

The proper cleaning and maintenance of a conductive floor is of extreme importance since the use of normal floor wax on conductive floors or floor mats can defeat their effectiveness. Personnel cleaning these items shall use the manufacturer approved cleaning agents and cleaning recommendations as minimum requirements. With guidance from the ET&V Officer, the Facility ESD Monitor will determine the cleaning regimen for the flooring and mats if the manufacturer's recommendations are not acceptable.

Conductive/dissipative floors or grounded conductive/dissipative floor mats shall have a maximum resistance to ground of 1×10^9 ohms and a minimum resistance of 1×10^5 ohms. The test methodology for flooring is found in ESD S7.1 "ESD Association Standard Test Method for the Protection of ESDS Items - Resistive Characteristics of Materials - Floor Materials".

Standard carpeting shall not be used in an EPA. Even the use of ESDP carpet woven with conductive fibers, which have previously been approved for use at JSC, can still be very problematic. If the conductive fibers are not dense enough, the resistance to ground will increase as the carpet wears. The selection of carpet in an EPA environment shall require pre-installation approval of the ET&V Officer.

Rationale: This requirement derives from ESD TR20.20-2008, Section 5.3.4 – Static Protective Floor Material. Refer to that source for further information.

6.7 Personnel Grounding Devices

Personnel grounding devices are the primary means of ESD control. For static charges generated during ordinary body movements, personnel-grounding devices provide a permanent path to ground. Such devices may take various forms such as:

Wrist Straps

Leg Straps

Heel Straps

Conductive Shoes

6.7.1 Wrist Straps

Wrist straps are considered to be the first line of defense against ESD and shall be required in the majority of ESDS work environments. Metallic contacts are preferred over conductive plastics. The wrist strap cuff shall always be in direct contact with the operator's bare skin. It must never be worn over clothing. Bead-type chain wrist straps are prohibited.

Wrist straps shall always be worn snugly against the skin and shall not dangle freely. The electrical integrity of each wrist strap shall be checked during initial certification and verified by the operator at the beginning of every shift during which it is used. A wrist strap checker specifically designed for that purpose shall be used to verify the wrist-strap is functional. The wrist straps shall be connected to ground using one common ground point for each workstation. ESD S6.1 “Grounding Recommended Practice” outlines the recommended grounding practices.

Continuous, in-line continuity checkers are highly recommended. (Reference ESD TR20.20-2008, Section 5.3.9 – Continuous Monitors). The electrical resistance of the wrist strap measured between the opposite hand and the (ungrounded) grounding end of the wrist strap assembly shall not exceed 9M ohms above the value of the incorporated current-limiting resistance. The static dissipative work surface material shall never be used as part of the series path to ground for a wrist strap.

More information on wrist strap testing and set up is available on ESDS1.1 “ESD Standard Test Method for the Protection of ESDS Items - Wrist Straps”.

Rationale: This requirement derives from ESD TR20.20-2008, Section 5.3.2 – Wrist Straps. Refer to that source for further information.

6.7.2 Leg Straps, Heel Straps, and Conductive Shoes

A conductive/dissipative floor and/or conductive floor mats are required when using leg straps, heel straps, and conductive shoes as acceptable alternatives to a wrist strap in those instances where the use of a wrist strap is impractical or unsafe. Examples of such instances would include working near moving conveyor belts or wave soldering machines and when working on large systems. The foot strap should have a built-in resistance of $1X10^6$ +/- 20 percent. If the resistance does not meet this recommendation, the value should be approved by the ET&V Officer.

The ET&V Officer shall measure the conductivity of leg straps, heel straps, and conductive shoes during the initial certification. The operator shall verify this conductivity for each work shift. Test methodology is found in ESD S9.1 "ESD Association Standard Test Method for the Protection of ESDS Susceptible Items – Footwear - Resistive Characterization".

> Rationale: This requirement derives from ESD TR20.20-2008, Section 5.3.3 – Footwear. Refer to that source for further information.

6.8 Equipment and Facilities Grounding

All permanent and semi-permanent metallic structures and test equipment utilized during handling or manufacturing of ESDS components or hardware shall be grounded using a common point ground. A major goal of this document is to ensure that all conductive materials are tied together at the same potential. An equal potential workstation is the secret to preventing damage to ESDS components.

The practice of having a separate ESD ground from the third wire (green) alternating current (AC) ground is wide spread but has the potential for damaging components because it places the operator and the work surface at a different ground potential with respect to any soldering irons and/or test equipment. The recommended practice is to use the third wire AC line ground for grounding all items at the ESDP workstation. When a separate grounding line is present or used in addition to the equipment ground, it must be bonded to the equipment ground at each ESDP station to minimize the difference in potential. ANSI EOS/ESD S6.1 "ESD Association Standard for the Protection of ESDS Items - Grounding-Recommended Practice" contains detailed hookup diagrams for ESDP workstations and support equipment.

The resistance of the conductor from the groundable point of the work surface, wrist strap, walking surface or other items to the common point ground should not be greater than 1.0 ohm. If a series resistor is used in the circuit, the total resistance shall be the value of the resistor.

The resistance of the conductor from the common point ground to the equipment ground should not be greater than 1.0 ohm.

The impedance (AC resistance) of the equipment-grounding conductor from the common point ground to the neutral bond at the main service equipment should not be greater than 1.0 ohm.

Each ESDP workstation should have a grounding block that provides sufficient wrist strap connections for all potential users. These grounding points shall not utilize portions of the protective work surface as a series element to complete the ground circuit. Receptacle grounds in an EPA shall be verified at least semiannually.

A good example of ESDP workstation setup is shown in Figure 6.5.1 Typical ESD Protective Station Grounding Systems and in ESD TR20.20-2008, Figure 13.

> Rationale: These requirements derive from ESD TR20.20-2008, Section 5.1.3 – Basic Grounding Requirements and from ESD TR20.20-2008, Sections 5.3.7 – Shelving and 5.3.8 – Mobile Equipment. Refer to those sources for further information.

6.8.1 Stools and Chairs

Personnel performing ESDS tasks while seated should use ESDP stools and chairs. Only chairs of metallic frame construction shall be used in an EPA. Class 1 facilities shall provide ESDP chairs or stools at the workstation if seating is required. Test methods are found in ESD STM 12.1 "ESD Association Standard Test Method for the Protection of ESDS Items – Seating – Resistive Characterization".

> Rationale: This requirement derives from ESD TR20.20-2008, Section 5.3.5 – Static Protective Seating. Refer to that source for further information.

6.9 Relative Humidity Control

Humidity control is important for an effective ESD program for two primary reasons;

At lower humidity levels (< 30% RH), the dissipation of commonly generated static charges does not take place, thus adding to the probability of ESD events.

Materials (such as pink poly) rely on the moisture in the air to combine with the material's antistatic agent to form a microscopic conductive layer over the entire surface of the material. At lower humidity, (typically below 15% RH) these antistatic materials can become charged, creating an ESD hazard.

The optimum relative humidity in an EPA is 50% (plus or minus 10%).

When humidity falls below 30% RH, ESDS devices and assemblies shall be processed using special controls and procedures such as air ionization and increased awareness of the greater potential for triboelectric charging. The Facility ESD Monitor must verify the humidity prior to each shift or operation if work is not shift based unless an automatic low humidity alarm system is monitoring the work area. It is highly recommended that facility air handlers include automatic humidifiers to maintain humidity control. EPAs shall control relative humidity within a range of 30 to 70 percent relative humidity.

> Rationale: This requirement derives from ESD TR20.20-2008, Section 5.3.15 – Humidity. Refer to that source for further information.

6.10 Air Ionizers

Air ionizers can neutralize the static charge on insulators or isolated objects by charging the molecules of the surrounding area that causes the accumulated charge to be neutralized. Air ionizers are generally used when it is not possible to properly ground everything at the workstation using previously described methods and equipment or as a back up to those methods.

As an example, most adhesive tapes are nonconductors and would require an ionizer to neutralize the charge on the tape if used in close proximity to ESDS devices. An ionizer shall be used at all, times when work is being performed in a Class 1 facility and must be available for use when needed in a Class 2 facility. Ionizers are specifically required for use in some manufacturing operations that generate static charges such as vapor degreasing, vacuum packing, spraying conformal coating, wave soldering, and the use of pressurized air guns. In addition, ionizers are a recognized static charge deterrent when humidity falls below 30 % RH. Any part sensitive to damage below 250 volts requires that an ionizer be used any time the part is removed from its ESDS packaging. Calibration of the air ionizer to verify balance and performance is required.

Rationale: This requirement derives from ESD TR20.20-2008, Section 5.3.6 – Ionization. Refer to that source for further information.

6.11 Hand Tools, Equipment, and Fixtures

Only ESDP hand tools should be used in the EPA. Manufacturer recommendations for usage and cleaning shall be followed. Component holding trays, microscopes, and other devices or fixtures commonly found in an EPA shall be constructed of metal or permanent static dissipative plastic and shall be maintained at ground potential by placing them on a grounded tabletop while in service at the workstation.

A good practice is to have the technician always touch the metal portion of a tool when picking it up. This practice will assure that any charged metal in the tool will discharge through the technician's wrist strap to ground.

Rationale: This requirement derives from ESD TR20.20-2008, Sections 5.5.2.2 – Hand Tools and 5.5.2.3 –Fixtures. Refer to that source for further information.

6.11.1 Soldering Equipment

Soldering iron and desoldering/rework system tips shall be grounded. The resistance between the tool's tip and its ground shall not exceed 10 ohms. All soldering iron tip grounds in an EPA shall be periodically verified. The test methodology is found in ESD DS13.1 "ESD Association Standard Test Method for Measuring Electrical Potential from Soldering/Desoldering Hand Tools".

6.11.2 Desoldering Equipment

Only ESD-protective desoldering equipment shall be used when working on ESD sensitive hardware. Only antistatic solder suckers made from metal or having at least a metallized plastic barrel and dissipative tip shall be used in an EPA.

6.11.3 Common Ground at the Workstation

All tools, equipment, or fixtures (such as lead forming tools, test fixtures, lights and solder pots, etc.) that are too large to be placed on the protective work surface shall be connected to the common ground point.

6.12 ESD Protective Packaging

Selection of the right packaging requires knowledge of the environment, the ESD susceptibility of the item, and the packaging materials. An overview of several types of packaging and common packaging for JSC applications is given below.

ESD protective packaging includes a number of different materials fabricated into various forms. These include:

Protective Bags and Pouches

Cushioned Packaging Materials

Conductive Foam

Conductive Shunts

Magazines, and Dipsticks and waffle packs

Tote Boxes and Other Holders

Dry Packs (maintains a sealed dry environment for devices)

Protective materials are capable of one or more of the following:

Limiting the generation of static electricity,

Safely dissipating electrostatic charges over their surface, and/or

Providing shielding from ESD or electrostatic fields.

To assure the bleed-off of triboelectric charges, the surface resistivity of any material that may come in contact with an ESDS item shall not exceed $1x10^{12}$ ohms/sq.

The Facility ESD Monitor shall make the final determination of the proper packaging at the work area with the concurrence from the responsible design-engineering project or office. The following minimum requirements shall be used at JSC.

If the packaged item is kept within an EPA, a low charging static dissipative material is typically acceptable.

If the packaged item is being transported outside of the EPA, then a static shielding material is required.

Care must be taken when using materials containing tertiary amines as they have been found to cause clouding of precision optics and damage to precision bearing assemblies due to out gassing. Studies have also shown that the tertiary amines in the film can cause a breakdown of polycarbonate parts. It is not recommended that any component extruded from polycarbonate be wrapped in pink poly or in any material using tertiary amines.

All tote boxes, bins, and trays (including printed circuit board carriers) shall be either static dissipative or conductive. In order to assure total ESD protection, all tote boxes shall be fitted with covers of equal conductivity as the bottom sections. The fit of the cover shall provide maximum conductivity across this interface.

A conductive tote box, bin, or tray with a conductive cover and a surface resistivity of $1x10^5$ ohms/square or less is an acceptable substitute for a shielded bag. Based on the requirements and guidelines found in this document, the responsible party for each facility or laboratory shall identify each ESD control work area. The responsible parties shall then develop an ESD Control Plan for each work area. This document provides guidance on how to comply with NASA Policy Directive 8730.5 (NPD-8730.5) that imposes ESD standard ANSI/ESD S20.20-2007.

Resistivity greater than $1x10^5$ ohms/square or are used without an adequately fitting conductive cover, then shielded bags shall be used to provide ESD Protection.

Rationale: The requirements for this section derive from ESD TR20.20-2008, Section 5.4 – Packaging Electronic Products for Shipment and Storage. Refer to that source for further information.

6.13 Carts, Wagons, and Trams

The use of carts, wagons, or trams to transport ESDS items not enclosed in ESDP material is only allowed if the vehicle either has conductive wheels or drags a metallic chain while being moved on conductive flooring. The operator is connected to the cart with a personal wrist strap, and the item is capable of being grounded as it is loaded or unloaded from the cart.

Carts, wagons, and trams used to carry ESDS materials properly wrapped to the requirements of this document are not required to operate on conductive flooring. The cart should have static dissipative mat covering the shelf surface that is grounded to the metal portion of the cart. The cart shall have a personnel wrist strap connection point and at least a 10-foot grounding strap for grounding the cart at its destination.

A cart carrying properly wrapped ESDS items shall be grounded prior to unloading any items from the cart. One method for accomplishing this grounding is to have the operator put on the workstation wrist strap and discharge the cart by touching it and its load before transferring anything to the workstation.

The ET&V Officer shall measure the effectiveness of the grounding of carts, wagons, and tram during the initial certification. The Facility ESD Monitor shall verify this effectiveness semi-annually. The resistance from the cart's grounding strap to any point on the static dissipative shelf surface shall be greater than $1x10^5$ but less than $1x10^9$ ohms. ESD S4.1 provides the requirements for testing the work surfaces for carts, wagons, and trams.

> Rationale: The requirements for this section derive from ESD TR20.20-2008, Section 5.5.6 – Storage Racks – Carts – Handling Fixtures and from ESD TR20.20-2008, Section 5.3.8 – Mobile Equipment. Refer to those sources for further information.

6.14 Temperature Chambers and Cooling Agents

Gas flow can be a significant generator of electrostatic charges. Adequate precautions must be taken when gas flow is utilized near ESDS items. Temperature chambers shall be equipped with grounded baffles and shelves to dissipate charges generated by circulated air. This shall be checked during initial certification and certified annually thereafter. The ESDS items themselves shall be contained within or be mounted upon conductive material.

When pressurized cryogenic cooling agents for localized cooling of specific circuit items are applied (for example, during troubleshooting), an approved ESDS safe cooling agent and spray apparatus shall be used.

The ET&V Officer shall make available triboelectric charge data for the brand and model of agent being used.

Prior to removal of an item from a chamber, a static field monitor shall be used to measure the surface charge on the item. If the static charge on an item cannot be determined, then an ionizer shall be used to dissipate any charge present.

> Rationale: The requirements for this section derive from ESD TR20.20-2008, Sections 5.5.2, 5.5.4 and 5.5.5 that cover grounding practices and the ESD hazards of large equipment. Refer to those sources for further information.

6.15 Cleaning ESD Protective Areas

Only manufacturer approved antistatic surface cleaners and materials shall be used for cleaning up minor dirt accumulations in a static protected area. Based on the manufacturer's recommended frequency, mats should be periodically cleaned using solvents or cleaning agents approved by the ET&V Officer. The use of excessive amounts of approved cleaners or vigorous rubbing shall be avoided in any EPA. When periodic cleaning is performed, it should normally be done at the end of the workday. ESDS items shall not be handled in an ESDP workstation while cleaning is in progress. The Facility ESD Monitor should resolve any questions concerning cleaning procedures.

Rationale: The requirements for this section derive from ESD TR20.20-2008, Section 5.3.1.14 – Maintenance. Refer to that source for further information.

6.16 Cleaning ESD Sensitive Items

Only natural fiber brushes shall be used for cleaning ESDS items unless a synthetic fiber has been qualified to be non-charging. Synthetic fibers, not certified specifically for use in ESDS device processing, are prohibited because of their propensity to triboelectric charge. Brush cleaning of ESDS subassemblies shall be performed while the subassembly is submerged in an approved cleaning fluid or solvent. Approved cleaning solvents are those specified in NASA-STD-8739.3, Table 6-1, "Solvents and Cleaners" or other NASA approved chemicals for the purpose of cleaning electronic components.

Cleaning ESDS items with a cotton swab (Q-tip or the equivalent) either dry or soaked in an approved solvent is permissible. Automatic machine cleaning of assemblies requires the use of an ionizer to neutralize any generated charges. Caution must be taken not to touch a cleaned item prior to assuring that all generated charges have been equalized.

When using compressed air or gases to clean ESDS items or to operate a heat pencil, a charged plate monitor shall be used to determine if charged particles are being generated from the airflow. If charging is occurring, an ionizer shall be inserted in the line of the air hose near the orifice to prevent charge generation.

6.17 Electrostatic Detectors, Monitors, and Voltmeters

Electrostatic detectors range from tools intended for performing ESD surveys to constant monitoring systems that will detect the presence of a charged object entering an EPA or the proper connection of a wrist strap. Additional equipment that may be needed for periodic facility surveys include a field monitor, a surface resistivity meter, and an ion balance meter.

Rationale: The requirements for this section derive from ESD TR20.20-2008, Section 5.3.9 – Continuous Monitors. Refer to that source for further information.

6.18 Contamination Control

Before using a humidifier, air ionizer, static dissipative wrap or cushioning materials, cleaning agent, or solvent on an ESDS subassembly or assembly, the item's Contamination Control Plan must be reviewed to verify that ESD protection methods do not violate the cleanliness requirement.

6.19 Clothing Requirements

Most personal clothing can generate static charges. Wearing an outer garment designed to reduce the charge build-up can control this problem. All personnel handling unprotected ESDS components or involved in the assembly or test of circuit-board assemblies shall wear static dissipative smocks as an outer garment. Where sleeves extend beyond the outer garment, the sleeves shall be rolled up or otherwise contained under the outer garment. Neckties and badges or other dangling articles shall be contained or removed.

6.19.1 Recommended Resistance Range

Garments, gloves, and finger cots shall be fabricated of qualified static dissipative materials with a resistivity range from $1x10^5$ to $1x10^{11}$ ohms/sq.

6.19.2 Clean Room Considerations

When procuring ESDP clothing, special consideration must be given to the clean room requirements of your work area. The need to protect the work area from lint, small pieces of conductive debris, or surface finish/sizing chemicals will dictate which type of garment is needed.

6.19.3 Cleaning

To prevent contamination of hardware and to maintain the garment’s static dissipative characteristics, garments shall be cleaned on a periodic basis or when visibly soiled. A cleaning process that does not compromise the static dissipative characteristics of the garment shall be defined using the manufacturers’ recommendations as the minimum requirement. If the manufacturer’s recommendations are followed, the cleaning process must be certified initially by the ET&V Officer. The resistivity of the garment shall be verified after each cleaning.

Materials made using conductive carbon threads are preferred because washing should have little negative effect on the static dissipative characteristics of the garment.

> Rationale: The requirements for this section derive from ESD TR20.20-2008, Section 5.3.13 – Garments. Refer to that source for further information.

7.0 OPERATING PROCEDURES:

7.1 Drawing Requirements and Identification of ESD Sensitive Items

An appropriate ESD warning symbol shall identify all new hardware built after the implementation of this standard, if the documentation indicates that the hardware contains ESDS items. This documentation includes, but is not limited to, assembly drawings, installation drawings, Type A and B Test Procedure Sheets, and test procedures.

Rationale: The requirements for this section derive from ESD TR20.20-2008, Section 5.3.14.1 – Marking of Assemblies and Equipment. Refer to that source for further information.

7.2 Marking of Assemblies, Subassemblies and LRUs

This ESD warning symbol is applicable to all assembly levels up to, but not including, the assembly that provides greater than Class 3 ESD protection (not sensitive below 16,000 volts). Items that are ESDS shall be marked with the hand symbol (Figure 7.2.1) below as directed by EOS/ESD S8.1 “EOS/ESD Association Standard for the Protection of ESDS Items – Symbols – ESD Awareness”.

When the physical size or available space of the item precludes the above described marking, the symbol shall be placed on the unit package of all ESDS exterior containers per MIL-STD-129, Section 5.2.20.2, Intermediate and exterior containers. The tag shall have an appropriate caution note as specified above and specific instructions, if required.

Figure 7.2.1 ESDS8-1-2001 ESD Susceptibility Symbol

7.3 Classification of Part ESD Sensitivity

Generally, ESD sensitivity of an electronic part, subassembly, or LRU is found on the data sheet or other accompanying paperwork. Any electronic component, subassembly, or LRU that has an unknown ESD sensitivity either must be handled or documented as a Class 1 part (most sensitive) or must have an engineering determination made of its classification. One available method of determination is to use ESD TR20.20-2008 Handbook Tables 2 and 3, which provide general part types that, are sensitive between 0–1,999 volts and 2,000-3,999 volts. All microcircuits qualified to MIL-PRF-38510 and semiconductors qualified to MIL-PRF-19500 are tested for ESD sensitivity.

7.3.1 ESD-Sensitivity Classification

ESDS items are classified in ANSI/ESD STM5.1 to their human body model ESD withstanding voltage threshold as shown in Table 7.3-1.

JSC Avionics Systems Division (EV) shall assist NASA and contractor organizations in determining the ESD-sensitivity of any device or LRU interface. Additionally, JSC Avionics Systems Division (EV) will provide technical expertise for ESD-related problems and procedure development.

Table 7.3-1 ESD Sensitivity Classification

Classification

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

7.3.2 ESD-Sensitivity Markings

Although actual part marking will most likely not be present, the classification of the part should be documented on the packaging and on the Certificate of Compliance (C of C) for each part number . The Qualified Manufacturers list provides the classification for each part number. If the part is marked, then a single diamond signifies a Class 1 part (sensitive to voltages ranging from 0-1,999 volts), two diamonds a Class 2 part (sensitive to voltages between 2,000-3,999 volts), and no marking signifies a Class 3 part (only sensitive to voltages over 4,000 volts).

7.4 Packaging Identification of ESD Sensitive Items

To ensure that all personnel who handle ESDS items are aware of an item's static sensitivity, the items and their protective packaging shall be suitably identified either by the part manufacturer or by the receiving organization prior to acceptance. All packaging containing ESDS items shall be prominently marked with the symbol shown in Figure 7.2.1 and shall follow the marking guidelines provided in ESD TR20.20-2008, Section 5.3.14.2. In addition, if the item's sensitivity is Class 1 and the manufacturer's marking or datasheet does not provide resolution of the breakdown voltage as defined in Table 7.3-1, then the organization using the item shall determine the item's ESD sensitivity, and they shall clearly mark its sensitivity on the package and accompanying paperwork.

Rationale: The requirements for this section derive from ESD TR20.20-2008, Section 5.3.14.2 – Marking of Packaging. Refer to that source for further information.

7.5 Shipping and Receiving

The shipping and receiving area is not required to be designated as an EPA as long as items marked as ESDS are left unopened in their protective packaging. Only trained and properly grounded personnel at an ESDP workstation shall open the inner packaging of an item marked ESDS.

7.6 User Receiving Inspection

Properly trained and grounded operators at an ESDP workstation must perform incoming inspections. All ESDS items, including those with Class 3 sensitivity, that are received without proper ESDS packaging or which exhibit evidence of packaging damage or tampering shall be rejected. Procurement and Quality Assurance must be notified of any violation in order for corrective actions to be initiated.

All ESDS items received from vendors, suppliers, subcontractors, etc., shall have been packaged in ESD protective containers and materials that meet the intent of MIL-E-17555, Section 3.11.10, Sensitive Electronic Items. All protective folders or envelopes holding documentation (lot travelers, etc.) shall be made of non-static-generating material.

When unpacking ESDS items that are not protected by static shielding material, an operator shall wear an approved wrist strap or other approved personal grounding device. All unpacking of ESDS items shall be performed in an EPA if the item is or will be outside of ESDP packaging.

The following materials are unacceptable and are explicitly prohibited from use in the immediate packaging or shipping container holding ESDS items even when they are properly protected:

Untreated Styrofoam®, polyfoam or polystyrene sheets, block inserts, and untreated pebbles or peanuts

Untreated plastic boxes

Static-generating plastic wrap, bags, or bubble pack

Untreated magazines, chutes, and carriers

Any tape or adhesive label unless dispensed in the presence of an ionizer or other method that will neutralize any generated charge. ESD safe tapes are available but even they may generate a charge when removed from a box after use.

Packaging and Shipment of ESDS Items

All ESDS items shall be enclosed in static shielding material whenever they are moved outside of an EPA.

Packaging for ESDS components and hardware leaving an EPA shall comply with the requirements detailed in ESD TR20.20-2008, Section 5.4, “Packaging Electronic Products for Shipment and Storage”. The materials used for packaging ESDS piece parts or hardware shall meet the requirements for the intended application based on criteria and standards called out in Section 5.4 of ESD TR20.20-2008.

7.7 Printed Circuit Board Level ESD Protection

While it is kept at an ESDP workstation for assembly, a circuit board containing ESDS devices shall be enclosed in a labeled static dissipative bag or shall be placed in a tote box when not being actively worked on. When the board leaves an EPA, it shall be protected in some form of static shielding container. All operations on the board shall be performed following appropriate ESDP procedures as described for individual ESDS items.

7.8 Storage of ESDS Hardware

All ESDS items in storage outside of an EPA shall be enclosed within approved ESDP packaging. ESDS items shall not be transported or stored in trays, tote boxes, vials, or similar containers made of untreated plastic material unless the items are first protectively packaged in ESD shielding material. All bond rooms shall provide an area to safely maintain ESDS items.

8.0 LINE REPLACEABLE UNIT ESD REQUIREMENTS:

An electronic assembly manufactured with a conductive outer enclosure should be ESDS only through contact with the exposed connector pins. If conductive or static dissipative caps cover the connectors, the box forms a Faraday cage around the internal ESDS components. A charge on the box should not cause damage to the internal components as long as the Faraday cage is intact and the charge is removed prior to mating any connectors. Whether in a launch vehicle or in a test configuration simulating flight conditions, all LRU installed in their normal flight configuration, with all connectors mated and/or covered are not considered ESDS unless analysis or testing has shown otherwise.

ESD precautions shall be implemented just prior to removal of a mating connector or connector caps. Exposed connector pins shall not be touched, and any testing or troubleshooting shall not be performed unless the operator and the box are at the same ground potential.

8.1 Interconnecting Cables

Tests conducted on cables have shown that a charge of several hundred volts can be generated on the conductors of a cable as the cable is flexed, unwrapped and, handled in a manner similar to what would occur during cable installation in a vehicle. This charge, which is generated by the triboelectric effects of the wire and its insulation, can potentially damage sensitive devices that would ultimately be connected to the cable.

Prior to the initial mating of newly installed cables, the connector pins and cable shield shall be grounded to discharge any electrostatic potential. An existing cable that is connected to another LRU does not require shorting prior to mating. When installing test equipment to flight hardware, the cables shall be installed to the non-flight equipment prior to the flight equipment.

8.2 Mounting and Unmounting Line Replaceable Units

As noted in the previous paragraph, an LRU with protective connector caps is not considered ESDS, but it is highly recommended that personnel be grounded throughout the LRU installation or removal process.

The use of a wrist strap in a spacecraft shall be regulated by the need to protect metal surfaces from scratches caused by alligator clips on soft metals and the knowledge that conductive debris is generated by the teeth of the clips. In addition, the working space may be too constrained to wear a wrist strap. In these cases, the operator shall use some other means to ground themselves with the LRU and connector prior to mating or demating.

The following guidelines should be used in establishing a procedure for handling LRUs that have been determined to be safe from ESD damage when all the connectors are protected.

When it arrives at the equipment rack with the LRU, the mobile cart should be tied to ground. If the LRU cannot be grounded through this procedure, then the operator or technician should momentarily ground the LRU by touching it with one hand and a grounded conductive surface with the other hand.

The technician verifies that conductive or dissipative covers for all connectors are secured in place.

Prior to moving the LRU from the cart, all personnel should momentarily ground themselves by touching a grounded object.

The LRU may be moved to the equipment rack without the use of a grounded wrist strap.

Prior to removing any connector covers, the technician shall be wearing a grounded wrist strap or using another grounding method.

The procedure for removing an LRU is the reverse of the procedure described above. A grounded wrist strap shall be worn prior to removing a connector.

When removing a connector from a non-ESDS LRU that is directly wired to a known ESDS LRU, the technician shall comply with the requirements of this section. When a patch-panel/breakout box has been installed into the wiring harness of an ESDS LRU, all operations performed using the breakout box require that the operator be grounded and that a sign be placed at the worksite warning of the ESD damage concern.

8.3 Determination of an LRU’s ESD Sensitivity

For all new flight hardware designs, the hardware design group shall determine if an assembly is ESDS. The hardware shall be properly marked and documented as Class 1, 2, 3, or non-ESDS, and the proper procedures for handling and packaging shall be provided.

All LRUs with an unknown ESD sensitivity shall be handled as ESDS, Class 2.

Hardware handled by the crew during flight should not be ESDS. Even for flight items known to be ESD immune, it is highly recommended that these items be transported in ESDP materials. Static generating materials are a hazard if they come into close proximity to any ESDS hardware.

If the outer case of an LRU has been opened and it contains parts classified as ESDS, it shall be handled as an ESDS item in accordance with the requirements of this document.

8.4 Box Level Testing to Determine the ESD Sensitivity of Flight Hardware

LRU or subassembly level ESD testing can be performed when verification of a design “safe threshold” limit is required to be verified by the hardware owners. Guidance for the selection of test methods at the subassembly or assembly levels can be located in IEEE-STD-C62.38-1994, IEEE Guide on Electrostatic Discharge ESD Withstand Capability Evaluation Methods (for Electronic Equipment Subassemblies). Acceptable test methods for all levels may be located in

ANSI C63.16-1993, American National Standard Guide for Electrostatic Discharge Test Methodologies and Criteria for Electronic Equipment, and/or IEC 61000-4-2, Electromagnetic Compatibility (EMC) – Part 4-2: Testing and Measurement Techniques – Electrostatic Discharge Immunity Test. Before testing is attempted, a complete test plan should be developed with well-defined objectives. The proposed test plan shall be reviewed JSC Avionics Systems Division (EV).

8.5 Analysis to Determine the ESD Sensitivity of Flight Hardware

Analysis may be used to satisfy verification of a design "safe threshold" limit. JSC Avionics Systems Division (EV) should be contacted for information and guidance in the performance of any analysis effort for the purposes of this paragraph.

9.0 ELECTROSTATIC DISCHARGE DESIGN GUIDE FOR PROTECTION OF ELECTRONIC EQUIPMENT AND CIRCUITS

9.1 Introduction

ESDS items are classified in ANSI/ESD STM5.1 to their Human Body Model (HBM) ESD withstanding voltage threshold as shown in Table 7.3-1, Section 7.3.1. These classification levels shall be used to ensure that the ESD control program, design hardening, protected areas, and handling procedures provide the requisite levels of ESD protection in accordance with the requirements of this standard.

The discharge model is typically represented by a voltage source feeding the charging network (consisting of resistors/capacitors) as stated in internationally recognized ESD standard IEC 61000-4-2. IEC 61000-4-2 is a system level standard used to model ESD events from human contact.

9.2 Characteristic of the ESD Waveforms

As discussed earlier, the IEC 61000-4-2 standard is intended to simulate a person discharging into a system while holding a metal object. The circuit diagram for the IEC pulse source from the specification is shown in Figure 9.2.1: IEC 61000-4-2 schematic as shown in specificationFigure 9.2.1, and a schematic view of the waveform is shown in Figure 9.2.2.

5)

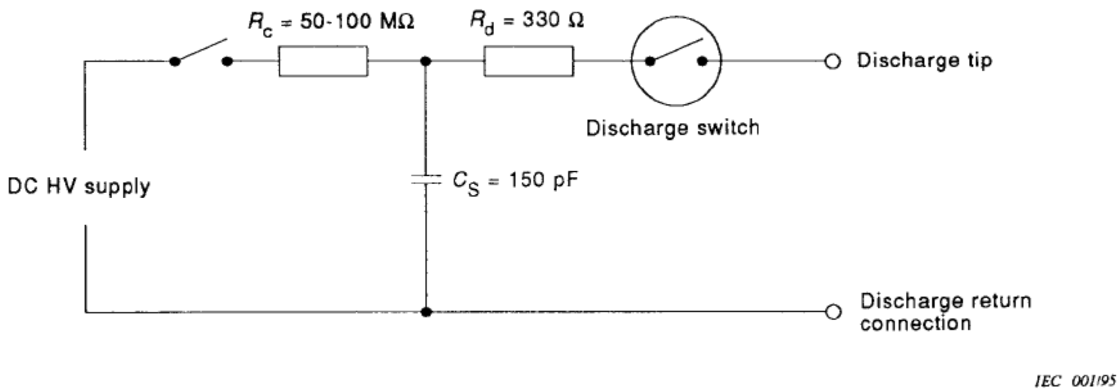

Figure 9.2.1: IEC 61000-4-2 schematic as shown in specification

Notes:
Rc: Charging Resistor
Cs: may include lumped, distributed, and stray capacitances depending on the particular ESD simulator construction
Discharge switch is not used for the air discharge test method.

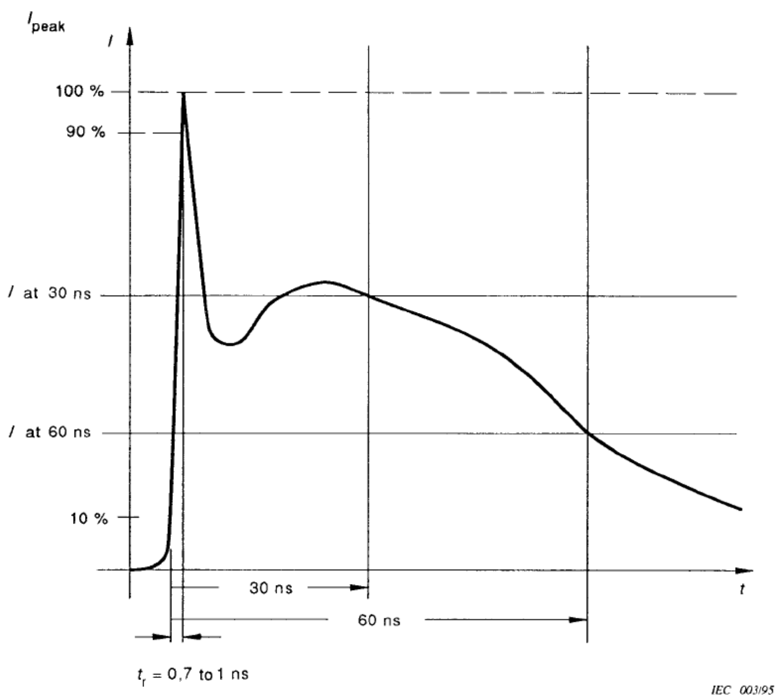

Figure 9.2.2: Schematic diagram of the IEC waveform

However, there is a fundamental difference between system level and device level testing. The individual model and its waveform are associated with each standard. Each of the standards is characterized by a capacitor that is charged and a discharge path.

The HBM standard, the most popular device level test model, consists of a person's capacitance to their surroundings, approximately 100pF, and the HBM standard uses this value to represent a person and the discharge path includes a person's skin resistance and the resistance of the spark, which has been approximated as 1500Ω. The typically circuit diagram for HBM is shown in Figure

9.2.3. An actual HBM current waveform has similar characteristics of the IEC waveform. However, the IEC waveform delivers the amount of energy that is much larger than a HBM pulse.

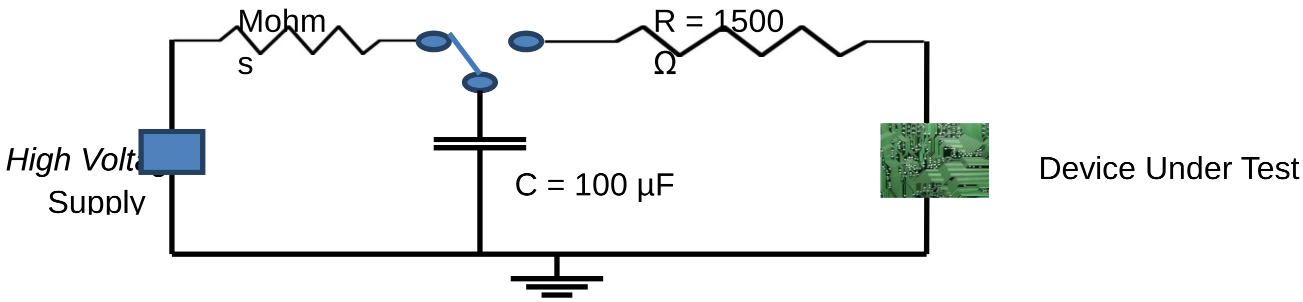

Figure 9.2.3: Basic circuit diagram for HBM

9.3 ESD Protection Circuitry

In general, various protection networks have been developed to protect sensitive electronic parts. These circuit protection networks provide limited protection against ESD. Although protection circuitry of some devices is improving and protection to 4,000 volts appears to be achievable for some MOS devices (Mil-HDBK-263B). However, electrostatic potentials of tens of thousands of volts can be generated in uncontrolled environments.

9.4 Protection Circuit Elements

The protection elements and their design parameters have to be optimized via an iterative procedure. The chosen design should be implemented, tested to failure, and the failure mode determined. Then a redesign to strengthen the failed structures can be undertaken, and the entire procedure repeated until the desired level of protection has been achieved. The optimization process starts with the analysis of established ESD protection elements, and design of ESD protection networks. The protection elements include diodes and resistors which are discussed below.

9.5 Diodes

A typical circuit that can be used for clamping voltages employs reverse biased diodes from the input line to the voltage rail and to ground. This ESD protection circuit must ensure that the voltage excursions on the input line are limited. The diodes must also have a low level of residual current, and the capacitance must be low to ensure that the frequency response / data rate and other input parameters are not impaired.

9.6 Resistors

Resistors have been used in ESD protection networks for many years, and when properly employed, they can enhance the input protection capability of certain networks. Two major classes of resistors are the diffused and the polycrystalline silicon (poly) types. Studies have shown that protection networks employing poly resistors connected directly to the input bond pad were more susceptible than networks that used diffused resistors. Thus, if resistors are required as part of an ESD protection network, only the diffused type should be considered. Also, the layout of the resistor should avoid 90° turns or any other geometry that could result in non-uniform current and electric field distributions.

9.7 ESD PCB Design

PCB design plays an important role in developing system immunity to ESD. The traces on a PCB are antennas for ESD-generated fields. Those connected to high impedance devices are antennas for electric fields, while those in low impedance circuit loops are antennas for magnetic fields. To minimize the coupling to these antennas, line lengths must be kept as short as possible and loop areas must be kept as small as possible. Lines longer than a few centimeters and loop areas larger than a few centimeters square can receive significant ESD noise.

9.8 Protection Network

Manufacturers have incorporated protection circuitry on most MOS devices such as diodes, transistors, and many other devices. The purpose of these protection networks is to reduce the voltage and energy flowing into an electrical circuit to levels sufficiently low to avoid damage to parts at the assembly levels. Differences in fabrication processes, design philosophies and circuitry have resulted in different protection networks. The following are some general guidelines to implement protection networks.

(a) The network should defend against threats to all pin combinations.

(b) The network should defend against both polarities applied ESD transient.

(c) The design must be insensitive to slight misalignment and process variations.

(d) Use diffused resistors instead of poly resistors.

(e) Use poly tabs between metal-diffusion contacts.

(f) Avoid thin oxides on protection network elements.

(g) Allow adequate contact-to-diffusion edge spacing.

9.9 ESD Testing

This section describes methodologies for ESD testing of electronic equipment. The test methods and parameters described herein are chosen for standardization and repeatability of test results. This section also recommends test criteria for evaluating equipment exposure and response to ESD.

The nature of the ESD event has resulted in the following two testing philosophies:

Air discharge test

Contact discharge test

The goal in both cases is to determine the immunity of the equipment under test (EUT) to an ESD event.

9.10 Test Setup

A typical test setup is shown in Figure 9.14.1as seen in ANSI C63.16 and IEC 61000-4-2 documents.

9.11 ESD Test Simulator

The ESD simulator is capable of generating the ESD waveforms and should meet required specifications at any specified repetition rate used for compliance testing. The circuit diagram of the ESD simulator is shown in Figure 9.2.3. The ESD simulator has consistence parts of the following:

Charging Resistance, Rch

Energy storage capacitance, Cs

Discharge resistance, Rd

Discharge switch for contact discharge testing

Interchangeable discharge tip (air/contact discharge tips)

Discharge return path

9.12 DC power source

JSC lab uses High Voltage technologies ESD simulator as shown below and are capable of simulating to 16KV level.

1 ESD3000DM1 discharge module to ESD3000 in accordance with IEC 61000-4-2 (human body discharge simulation)

Revised: 05.May 2006

ESD3000DM1	ESD3000
	

1.1 Technical data

Standard	IEC/EN 61000-4-2	
Energy storage capacitance	150 pF	± 10%
Discharge resistance	330 Ω	± 10%
Holding time (drop to 95%)	better than 5 s	
Current rise time, 2 Ω load	0,7 to 1 ns	
First current amplitude into 2 Ω „contact discharge“	7,5 to 30 A	± 10%
Current amplitude at 30 ns	4 to 16 A	± 30%
Current amplitude at 60 ns	2 to 8 A	± 30%
Voltage range „air discharge“	0.2 to 16 kV	± 10%
Voltage range „contact discharge“	0.2 to 10 kV	± 10%
Repetition of the discharges	0.05 up to 30 s or single discharge „Man“	
Voltage range „contact discharge“	0.2 to 10 kV	± 10%

9.13 Test Levels

See section 7.3.1 for EUT classification and required test levels.

9.14 Selection of Test Points

The test points to be considered may include the following locations as example if applicable:

Points on metallic sections of a cabinet which are electrically isolated from ground

Any point in the control or keyboard area and any other point of human operation such as switches, knobs, buttons, and other operator-accessible areas– indicators, LEDs, slots, grilles, connector hoods, etc.

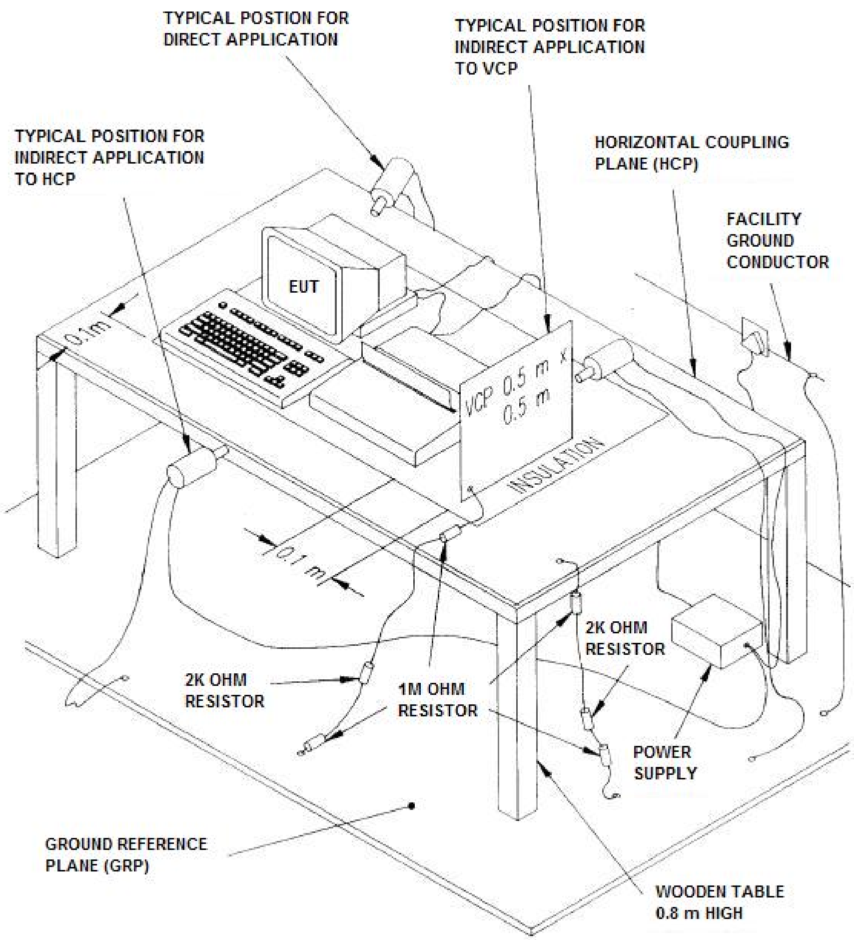

Figure 9.14.1: Typical Test Setup for Table Top Equipment

9.15 Test Planning

The test plan/procedure must include the EUT operational mode(s), applicable ESD requirement, test point selection and all necessary EUT information.

In general, the direct application of the ESD event shall be applied only to those points and surfaces of the EUT which are accessible to persons during normal use, as shown in Figure 9.14.1.

Discharges to objects placed or installed near the EUT shall be simulated by applying the discharges of the ESD generator to a coupling plane, in the contact discharge mode, as shown in Figure 9.14.1.

Table 9.15-1through Table 9.15-3show examples of general test planning templates and can be use as a test result template as well.

Table 9.15-1: ESD – Contact Discharge

EUT Operational mode:	Power off									
Number of Discharges:	10			Discharge Polarities:				Positive/Negative		
Discharge Resistance:	330 ohm			Energy Storage Capacitance:				150 pF		
Application:	Direct application									
Location	Discharge Voltage levels (kV)									
	2	-2	4	-4	6	-6	8	-8	Max	-Max
Location 1	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
Location 2	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
Location 3	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
P: Pass F: Fail										

Table 9.15-2: ESD – Contact Discharge

EUT Operational mode:	Power on									
Number of Discharges:	10			Discharge Polarities:				Positive/Negative		
Discharge Resistance:	330 ohm			Energy Storage Capacitance:				150 pF		
Application:	Direct application									
Location	Discharge Voltage levels (kV)									
	2	-2	4	-4	6	-6	8	-8	Max	-Max
Location 1	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
Location 2	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
Location 3	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
P: Pass F: Fail										
Table 10.3.5.3: ESD – Contact Discharge										
EUT Operational mode:	Power off									
Number of Discharges:	10			Discharge Polarities:				Positive/Negative		
Discharge Resistance:	330 ohm			Energy Storage Capacitance:				150 pF		
Application:	Indirect application									
Location	Discharge Voltage levels (kV)									
	2	-2	4	-4	6	-6	8	-8	Max	-Max
HCP	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
VCP	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
P: Pass F: Fail										

Table 9.15-3: ESD – Contact Discharge

EUT Operational mode:	Power on									
Number of Discharges:	10			Discharge Polarities:				Positive/Negative		
Discharge Resistance:	330 ohm			Energy Storage Capacitance:				150 pF		
Application:	Indirect application									
Location	Discharge Voltage levels (kV)									
	2	-2	4	-4	6	-6	8	-8	Max	-Max
HCP	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
VCP	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F	P/F
P: Pass F: Fail										

APPENDIX A ACRONYMS, TERMS, AND DEFINITIONS

Within this document, the following terms appear.

TERMS AND DEFINITIONS

Most of following definitions are taken from ESD ADV1.0-2004. The other definitions are standard industry terms used in dealing with ESD.

Term	Definitions
Air Ionizer	A source of charged air molecules (ions). The positive ions are attracted to negatively charged bodies and the negative ions to positively charged bodies, resulting in charge neutralization.
Antistat, Antistatic Agent	A chemical compound which when impregnated in, or topically applied to, a primary material or substrate renders the primary material antistatic. Topical antistats function in two different ways. First, they reduce the material's coefficient of friction by increasing surface lubricity. This tends to reduce the maximum potential charge that can be generated by triboelectric effect. Secondly, they increase surface conductivity, thus allowing any charges to be dissipated more rapidly. However, most topical antistats function by absorbing moisture (hygroscopic) from the ambient air and forming a conductive water layer on the material's surface. These types become less effective below 30% relative humidity.
Antistatic	Usually refers to the property of a material that inhibits triboelectric charging. Note: A material's antistatic characteristic is not necessarily correlatable with its resistivity or resistance.

Term	Definitions
Antistatic Plastic	Any specialized plastic that reduces triboelectric charging. Although some antistat agents, especially hygroscopic ones, might slightly increase the surface conductivity of the base plastic, the resultant conductivity is usually insufficient to provide ESD shielding. Antistatic plastics usually follow the requirements of MIL-PRF-81705, equal to or greater than $1x10^5$ ohms/square but less than $1x10^{12}$ ohms/square or a volume resistivity equal to or greater than $1x10^4$ ohm-cm but less than $1x10^{11}$ ohm-cm.
Black Box	An assembly or sub-assembly encased in a manner of which only interface connectors are available to the outside world. The box may be any color.
Charged Device Model	A model characterizing an ESD event in which a device isolated from ground is charged and is subsequently suddenly discharged by touching a conductive surface.
Common Point Ground	(1) A grounded device where two or more conductors are bonded. (2) A system or method for connecting two or more ground conductors to the same electrical potential.
Conductive	A property of materials which are either metal or impregnated with metal, carbon particles or other conductive materials, or whose surface has been treated with such materials through a process of lacquering, plating, metalizing, or printing. A conductive material for static control purposes shall have a surface resistivity less than $1x10^5$ ohms/square or a volume resistivity of less than $1x10^4$ ohm-cm. A conductive material is not necessarily antistatic.
Dissipative Material	A material that has a surface resistance greater than or equal to 1×10^4 but less than $1 X 10^{11}$ ohms or a volume resistance greater than or equal to 1×10^4 ohms but less than $1 X 10^{11}$ ohms.
Electrostatic Discharge (ESD)	The rapid, spontaneous transfer of electrostatic chare induced by a high electrostatic field. Note: Usually, the charge flows through a spark between two bodies at different electrostatic potentials as they approach one another.
Electrostatic Field	The region surrounding an electrically charged object in which another electrical charge will experience a force. Quantitatively, it is the voltage gradient between two points at different potentials.
Electrostatic Shield	A barrier or enclosure that prevents the penetration of an electrostatic field. This barrier must be solid metal sheet or wire mesh to be effective. An electrostatic shield may not offer much protection against the effects of electromagnetic fields.

Term	Definitions
Equipment Ground	(1) The ground point at which the equipment ground conductor is bonded to any piece of equipment, at the equipment end of the conductor. (2) The 3rd wire (green) terminal of a receptacle. (3) The entire low impedance path from a piece of electrical equipment to a hard ground electrode.
ESD Protective (ESDP)	A property of materials capable of one or more of the following: preventing the generation of static electricity, dissipating electrostatic charges over its surface or volume, or providing shielding from ESD or electrostatic fields. ESD safe materials are sometimes classified in accordance with their surface resistivities as either conductive or static-dissipative.
Electrostatic Protected Area (EPA)	An area, which is constructed and equipped with the necessary ESD protective materials and equipment to limit ESD voltages below the sensitivity level of ESD sensitive items, handled therein.
ESD Protective Clothing	Clothing manufactured from fabrics specially designed or treated to inhibit buildup of electrostatic charge.
ESD Sensitive (ESDS) Items	Electrical and electronic parts, assemblies, and equipment that are ESDS to discharge voltages less than 16,000 volts.
ESD Test & Verification Officer	S&MA will maintain an office that is responsible for inspection and certification of JSC facilities handling ESDS materials. (Defined in Section 3.1.1)
Facility ESD Monitor	Each organization responsible for an Electrostatic protected area shall have a Facility ESD Monitor to be responsible for assuring that area is in compliance. (defined in Para 4.5)
Ground	A conducting body, such as the earth or the hull of a steel ship used as a return path for electric currents and as an arbitrary zero reference point.
Ground Fault Circuit Interrupter	A device intended for the protection of personnel that functions to de-energize a circuit or portion thereof within an established period of time. It is activated when a current to ground exceeds some predetermined value that is less than that required to operate the over current protective device of the supply circuit.
Hard Ground	A connection to ground either directly or through a resistance less than 1 ohm.

Term	Definitions
Insulative Material	A material having a surface resistivity of at least $1x10^{12}$ ohms/square, or $1x10^{10}$ ohm-cm volume resistivity.
Ionization	The process by which neutral atoms or molecules, such as those in air, acquire a positive or negative charge. (Also air ionizer)
Latent Failure	A malfunction that occurs following a period of normal operation. Note: The failure may be attributable to an earlier electrostatic discharge event. The concept of latent failure is controversial and not totally accepted by all in the technical community .
Line Replaceable Unit (LRU)	A black box that can be replaced on the flight line with only common knowledge and tools.
Metallic Film Laminate Bags	ESD protective bags of a sandwich-type construction composed of various separate layers bonded together. The inside surface is usually an antistatic plastic, and another layer is a thin metal film. These bags are designed to provide protection against both triboelectric charging and external electrostatic fields and ESD events.
Soft Failure	Failure of an item for a limited period of time, after which the item recovers its ability to perform its required function.
Soft Ground	A connection to ground through impedance sufficiently high to limit current flow to safe levels for personnel (normally 5 milli-amperes). Impedance needed for a soft ground is dependent upon the voltage levels that could be contacted by personnel near the ground.
Static Decay Test	A procedure that specifies contact charging a material and measuring the decay time to a specific voltage. Decay to 10% of the initial voltage is frequently used.
Static Dissipative	A property of a material having a surface resistivity of at least $1x10^5$ ohms/square or $1x10^4$ ohm-cm volume resistivity, but less than $1x10^{12}$ ohms/square surface resistivity or $1x10^{11}$ ohm-cm volume resistivity.
Static Electricity	Electrical charge at rest. The electrical charge is due to the transfer of electrons from one body to another.

Term	Definitions
Static Shielding Material	Will protect ESDS components from both internal and external static charge. It keeps static from building inside a bag due to movement of the component (triboelectric charge) and shields the contents from external electrostatic fields and direct discharge. Shielding bags are often several layers thick. They should contain an antistatic inner layer (in contact with the component) and a conductive transparent metallic layer (often aluminum or nickel) toward the outside of the bag. Shielding bags tend to be of a black or silver semi-transparent color.
Surface Resistivity	The ratio of DC voltage to the current that passes across the surface of the system. In this case, the surface consists of a square unit of area. In effect, the surface resistivity is the resistance between two opposite sides of a square and is independent of the size of the square or its dimensional units. Surface resistivity is expressed in ohms/square. When using a concentric ring fixture, resistivity is calculated by using the following expression: Surface Resistivity S = (D2 + D1/D2-D1) *R Where D2 = Inside diameter of the outer electrode D1 = Outside diameter of the inner electrode R = Measured resistance in ohms
Tertiary Amines	An additive put in polyethylene film by some manufacturers to make it antistatic. These “polar solvents” can damage polycarbonate parts stored in such bags. Before using materials made antistatic using Amines, testing should be performed to determine the effect on the material being stored.
Topical Antistats	Chemical agents applied to surfaces of insulative materials, which will reduce the surface ability to generate static.
Triboelectric Charge	The generations of electrostatic charges when two pieces of material in intimate contact are separated (where one or both is an insulator). Substantial generation of static electricity can be caused by contact and separation of two materials or by rubbing two substances together.
Triboelectric Series	A list of substances arranged so that one can become positively charged when separated from one farther down the list, or negatively charged when separated from one farther up the list. The series main utility is to indicate likely resultant charge polarities after triboelectric generation. However, this series is derived from specially prepared and cleaned materials tested in very controlled conditions. In everyday circumstances, materials reasonably close to one another in the series can produce charge polarities opposite to that expected. This series is only a guide.

Term	Definitions
Volume Resistivity	The ratio of the DC voltage per unit thickness applied across two electrodes in contact with a specimen to the amount of current per unit area passing through the system. Volume resistivity is generally given in ohm-centimeters. When using a concentric ring fixture, resistivity is calculated by using the following expression: Volume Resistivity = (D12/4T) * R Where: D1 = Diameter of the inner electrode or disc R = Measured resistance in ohms T = Thickness of the specimen

ACRONYMS

The following acronyms are used in this document.

Acronym	Full Term
ESD	Electrostatic Discharge
ESDS	Electrostatic Discharge Sensitive
JSC	Johnson Space Center
LRU	Line Replaceable Unit
ORU	Orbital Replacement Unit
R&M	Reliability and Maintainability
EMC	Electromagnetic Compatibility
SM&A	Safety and Mission Assurance
ET&V	ESD Testing and Verification
EPA	Electrostatic Protected Area
QC	Quality Control
GFCI	Ground Fault Circuit Interrupter

APPENDIX B INFORMATIVE REFERENCES

The following documents, though not formally a part of this standard, amplify or clarify its content:

Rev / Date.	Document No.	Title	Source or Location
B/ 31 July 1994	MIL-HDBK-263	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)	http://www.dtic.mil/dtic/search/tr/tr.html