NASA GSFC Code 560 (Electrical Engineering Division)

Electrostatic Discharge (ESD) Control Plan

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Goddard Space Flight Center
Greenbelt, Maryland

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FOREWORD

This Electrostatic Discharge (ESD) Control Plan is modeled on the standards used by NASA Goddard Space Flight Center (GSFC) projects, which are NASA-STD-8739.7 for projects established before February 2002, and ANSI/ESD S20-20-1999 for projects established after February 2002.

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SIGNATURE PAGE

Reviewed by:

Vinod Patel 10-22-04

Vinod Patel Date
NASA GSFC, Code 562

Approved by:

John H. Day 10/25/04

John H. Day Date
NASA GSFC, Code 560

Submitted by:

Marcellus A. Proctor 10/22/04

Marcellus A. Proctor Date
NASA GSFC, Code 562

ACRONYM LIST

ANSI – American National Standards Institute
CMOS – Complementary Metal Oxide Semiconductor
COTS – Commercial Off-the-Shelf
CRT – Cathode Ray Tube
EED – Electrical Engineering Division
ESD – Electrostatic Discharge
ESDCP – ESD Control Plan/Program
ESDS – Electrostatic Discharge Sensitive
GIDEP – Government/Industry Data Exchange Program
GSFC – Goddard Space Flight Center
I/T – Integration and Testing
IC – Integrated Circuits
MOS – Metal Oxide Semiconductor
MOSFET – Metal Oxide Semiconductor Field Effect Transistor
NMTTC – NASA Manufacturing Technology Transfer Center
PEMs – Plastic Encapsulated Microcircuits
PG – Procedures and Guidelines
QA – Quality Assurance
WI – Work Instruction

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1. PURPOSE

The purpose of this Electrostatic Discharge (ESD) Control Plan is to provide awareness and guidance for establishing, implementing, monitoring, and maintaining a work area that will reduce the probability of ESD damage to flight hardware. The scope of this control plan is intended to focus on four areas within EED in which ESD can be detrimental to flight hardware:

1. Design and development.
2. Parts (testing, handling, shipping, packaging, and receiving).
3. Manufacturing.
4. Integration/testing (I/T).

1.1 Background on ESD

Electrostatic discharge occurs when a charge imbalance causes electrons to flow, either between two different objects or on different areas in or on a single object. If the charge flows in an uncontrolled manner through an ESD-sensitive device (ESDS) or structure in a device, damage can result.

1.2 Devices Susceptible to ESD

Different devices are susceptible to ESD to various degrees due to their design. Table 1 lists the device structures that are incorporated into various devices types that are ESD sensitive.

Table 1. Representative ESD-Sensitive Electronic Devices List [2], [3]

Part Element	Part Type	ESD Susceptibility (Volts)	Failure Mechanism	Failure Indicator
MOS Structures	CMOS	250-3,000	Dielectric Breakdown	Short Circuit
Semiconductor Junctions	MOSFET, Schottky Diodes	100-200, 300-2,500	Thermal Breakdown	Short Circuit
Film Resistors	Thin and Thick	300-3,000	Dielectric Breakdown	Resistance Shift
Metallization Strips	Hybrid and Monolithic ICs	190-2,500	Metallization Melt	Open

1.3 Effect of ESD on Electronic Parts

ESD to electronic devices can occur at any point from manufacturing, testing, and assembly to installation into a spacecraft. Damage to an ESDS device by an ESD event is determined by the device's ability to dissipate the energy of the discharge or withstand the voltage levels involved. This is known as the device's ESD sensitivity.

Many advanced technologies, such as plastic encapsulated microcircuits (PEMs), are susceptible to failure at less than 100 Volts, and many disk-drive components have sensitivities below 10 Volts. To fit more circuitry into small packages, the spacing isolating circuitry has been reduced, making them more susceptible to ESD. A discharge of static electricity produces enough heat to burn through microelectronic architecture rated to withstand voltage in the order of Volts.

Numerous published papers from industry, military, and aerospace organizations, as well as alerts from the Government Industry Data Exchange Program (GIDEP), have described the failures of electronic parts due to ESD. The cost of not implementing effective ESD controls can be substantial in terms of funds lost for failed parts. Failure of a part may cost tens to hundreds of dollars, but failures occurring at the assembly level can range from tens to hundreds of thousands of dollars.

2. ESD CONTROL PLAN (ESDCP)

To be effective, every area within EED must assess its ESD requirements and determine what level of precaution is necessary to ensure that ESDS parts and assemblies are protected. This plan must be adjusted to suit each area's specific needs, but should follow basic guidelines set forth by ANSI/ESD S20.20-1999. This plan serves as a starting point to ensure that ESDS parts within areas of EED are protected.

2.1 Administrative Guidance

In developing any ESDCP, the following personnel within EED are essential in preventing ESD by assuming the responsibilities listed below:

1. The Division Chief is responsible for the following:

    a. Appointing an ESD Officer within EED to implement the ESD Control Plan and monitor ESD awareness and responsibilities for all personnel working in ESD-sensitive areas within EED.

2. The ESD Officer is responsible for the following:

    a. Assist Branch/Office Heads in the implementation of an ESD Control Plan for each ESD-sensitive area within EED.
    b. Providing resources to Branch/Office Heads towards training personnel and equipping areas with ESDS parts and assemblies to fulfill the ESD Control Plan.
    c. Establishing, maintaining, and monitoring metrics of ESD-sensitive areas within EED.

3. Branch/Office Heads are responsible for the following:

   a. Appointing an ESD Custodian/Lead to assume responsibility of ESD operations and procedures within the respective labs or work areas.
   b. Performing periodic spot checks of ESD areas within the Branch/Office.
   c. Providing resources to ESD Custodian/Lead to satisfy the requirements of ESD procedures and guidelines (PG).

4. The ESD Custodian/Lead is responsible for the following for lab personnel:

   a. Maintaining work instructions, drawings, and other documentation for ESD cautions, markings, and precautionary procedures.
   b. Ensuring that access to ESD-protected areas is limited to persons who have completed ESD training.
   c. Collecting and maintaining part ESD sensitivity data from supply vendors and manufacturers.
   d. Certifying that technicians, engineers, and authorized personnel in test and manufacturing labs or facilities are ESD trained.
   e. Implementing ESD precautionary handling and packaging procedures during receiving, processing, inspecting, and packaging.
   f. Implementing precautionary procedures when ESD-protected areas do not meet specifications.
   g. Marking ESDS assemblies, parts, and equipment with an ESD caution symbol in a readily visible position.
   h. Maintaining ESD procedures in Work Instructions (WIs).
   i. Auditing and certifying ESD-protected areas on a regular basis.

2.2 ESD Control Plan Technical Guidance

To be effective, an ESDCP must be comprehensive and adaptive to fit the needs of the project ESDS parts requirements. Older, less sensitive parts require minimum precautions, whereas parts that are susceptible to a few volts require extensive precautions. The requirements are based on an area sensitivity classification system, which lists four classes of sensitivity: [1]

- Class I areas contain parts with ESD withstand voltages ranging up to 1,999 Volts.
- Class II areas range from 2,000 to 3,999 Volts.
- Class III areas range from 4,000 Volts and up.
- Class IV areas do not contain devices that are sensitive to ESD damage or for non-project research and development.

Based on these classifications, each ESD-protected area should be classified according to the most sensitive device handled. For example, a device with an ESD withstand threshold of 100 Volts would be handled in a Class I area, and all other devices in that area would be handled the same way.

To determine the control measures needed for each sensitivity class, an ESD requirements matrix was developed. The matrix is separated into two categories: 1) research and development applications (non-space-flight), Table 2, and 2) space flight/potential space flight applications, Table 3.

The research and development matrix shows the minimum requirements needed for parts or assemblies being tested for research or self-training. The space flight/potential space flight matrix, however, requires more stringent requirements to ensure that flight parts are kept safe from accidental discharges while being stored, handled, and packaged. Replacement of damaged flight parts usually costs 10 times more than their equivalent commercial parts. Also, with the increased use of commercial off-the-shelf (COTS) parts for space flight applications, extra requirements are needed to ensure that these parts are not damaged or destroyed while being inspected or assembled.

Table 2. ESD Requirements Matrix for Research and Development Applications (Non-Space-Flight)

Requirements	Class I	Class II	Class III	Class IV
Personnel Training (A)	OP	OP	OP	NR
Auditing (A)	NR	NR	NR	NR
Protected Workstations (E)	OP	OP	OP	NR
Wrist Straps (E)	R	R	R	NR
Protective Clothing (E)	OP	OP	OP	NR
Conductive Floors (E)	NR	NR	NR	NR
Ionizers (E)	NR	NR	NR	NR
Foot Straps (E)	NR	NR	NR	NR
Humidity Monitors (M)	R	R	R	NR
Protective Bags (E)	R	R	R	NR
Work Mats (E)	R	R	R	NR
Sensitivity Marking (A)	OP	OP	OP	NR
Sensitivity Testing (M)	NR	NR	NR	NR
Finger Cots (E)	NR	NR	NR	NR
Seats (E)	NR	NR	NR	NR
Storage Equipment (E)	NR	NR	NR	NR

R = Required
OP = Optional (Consult ESD Custodian/Lead)
NR = Not Required
(A) = Administrative
(E) = Equipment
(M) = Monitors

Table 3. ESD Requirements Matrix for Space Flight/Potential Space Flight Applications

Requirements	Class I	Class II	Class III	Class IV
Personnel Training (A)	R	R	R	NR
Auditing (A)	R	R	R	NR
Protected Workstations (E)	R	R	R	NR
Wrist Straps (E)	R	R	R	NR
Protective Clothing (E)	R	R	R	NR
Conductive Floors (E)	R	R	R	NR
Ionizers (E)	OP	OP	OP	NR
Foot Straps (E)	OP	OP	OP	NR
Humidity Monitors (M)	R	R	R	NR
Protective Bags (E)	R	R	R	NR
Work Mats (E)	R	R	R	NR
Sensitivity Marking (A)	R	R	R	NR
Sensitivity Testing (M)	OP	OP	OP	NR
Finger Cots (E)	OP	OP	OP	NR
Seats (E)	OP	OP	OP	NR
Storage Equipment (E)	R	R	R	NR

R = Required
OP = Optional (Consult ESD Custodian/Lead)
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2.3 ESD Control Area Guidance

2.3.1 ESD-PROTECTED AREA

The major focus of this control plan is for each Branch/Office to establish an ESD prevention program for their respective ESD-protected areas. These areas should be established at any point where devices are handled wherever practical. Where full ESD-protected areas are not feasible, all safe-handling procedures should still be observed. There are six aspects to implementing an ESD-protected area:

- Area controls.
- Workstation controls.
- Personnel controls.
- Equipment controls.
- Storage/packaging.
- Training and maintenance.

2.3.1.1 Area Controls

The first level of ESD event control is the area or room in which devices will be handled. The ESD-protected area must be defined and marked with the appropriate ESD caution signs and barriers when handling ESDS parts and assemblies. Area-level ESD control is accomplished through the following methods:

- Relative Air Humidity – Humidity is an important factor in the generation of static electricity. As humidity increases, the surface resistivity decreases. This condition means that insulator materials rubbed together or pulled apart in a humid environment generate lower static charges than in a dry environment. It is recommended that relative humidity be maintained at an ideal range of 40% and 60% and a maximum range of 30% and 70%. To achieve this, a controlled humidifier is needed to monitor relative humidity throughout the ESD-protected area.

- Air Ionizers – In order to help rapidly dissipate any built-up charges, air ionizers spray the area in clouds of alternately charged ions (balanced to give a zero net charge buildup). While effective in open areas, these clouds are blocked by obstructions, so local measures are also needed.

- Floor Coverings – Conductive and dissipative flooring can be used to ground both personnel (in conjunction with appropriate footwear) and properly grounded, moving equipment. After each cleaning, it is recommended that conductive floor resistivity be verified and the results shall be recorded. The use of waxes and the buffing of conductive floors are prohibited. A notice stating these restrictions shall be prominently displayed in areas where conductive floors are used in conjunction with protective footwear.

- Grounding – Both third wire ac line ground and Earth-Ground/Quiet-Ground is acceptable for grounding all items at the ESD-protected workstation. When a separate grounding line is present or used in addition to the equipment ground, it should be bonded to the equipment ground at each ESD-protected work station to minimize the difference in potential.

2.3.1.2 Workstation Controls

The workstation requires special attention, as it is where ESDS devices are handled and therefore presents the greatest risk for ESD events. ESD protection efforts can be focused on three areas:

- Work Surface – Since this is the surface that will come in direct contact with ESDS devices, it should be covered with a grounded, dissipative material.

- Local Environmental Controls – Local air ionizers can be used to help control the buildup of charges, and should be used when insulating materials or charge-inducing equipment (e.g., CRTs) are present at the workstation.

- Grounding – The work surface, any conductive part of the work station, a dissipative floor mat (if the flooring is not dissipative), work chair or stool (through conductive casters or feet), and operating personnel (through ground straps) all must be tied to a common ground.

Below in Table 4 is a summary chart of recommended guidelines for ESD-protected areas, workstations, and tools.

Table 4. Recommended Guidelines for ESD-Protected Areas, Workstations, and Tools

Item	Recommended Guidelines
1. ESD-Protective Work Surface	Where unprotected ESDS devices are handled, a grounded static protective work surface with a resistance to ground of less than 10^9 Ω and bags less than 10^8 Ω are required.
2. ESD-Protective Flooring or Floor Mats	Grounded flooring or floor mats are only required when personnel or mobile ESD protective workstations utilize floor grounding methods. Suggested resistance limits: 10^5 to 10^{11} Ω.
3. Personnel Grounding	Each person handling or within 12 inches of unprotected ESDS devices shall be grounded using **EITHER:** **a) Wrist straps that will:** 1) Provide proper grounding from the user directly to ESD ground. 2) Have an integral resistance at the wristband end of the grounding wire that will limit current to less than 0.5 mA through the specific path that may be encountered. 3) Be worn by operators handling unprotected ESDS devices when seated. Suggested resistance limits: $0.8*10^6$ to $1.2*10^6$ Ω. **b) ESD-protective footwear (heel straps, toe straps, or shoes) that will:** 1) Provide a continuous electrical path from the user directly to the ESD-protective flooring or floor mat. 2) Be worn on both feet. 3) Limit to less than 0.5 mA through that specific path to ground at the highest power supply voltage that may be encountered. 4) **NOT** be relied upon for grounding of seated personnel. Suggested resistance limits: $0.8*10^6$ to $1.2*10^6$ Ω. Suggested resistance limit for seats: 10^7 Ω.
4. Static-Generating Sources and Charged Surfaces	a) Nonessential and personal items shall not be placed on ESD-protected work surfaces that are in use. b) No item or equipment, such as CRT monitors, with an electrostatic potential greater than ± 1,000 Volts (as measured with a field meter), shall be closer than 3 feet from unprotected ESDS devices. c) Operations, equipment, or clothing generating electrostatic potential greater than ± 1,000 Volts within 12 inches of unprotected ESDS devices shall be neutralized or reduced to less than ± 1,000 Volts. d) Charged items must not contact ESDS devices.
5. ESD-Protective Smocks	When ESD-protective smocks are worn, they should cover all personal garments above the waist except at the neck area. Suggested resistance limits: 10^5 to 10^{11} Ω.
6. Air Ionizers	Air ionizers may be used to reduce electrostatic potentials to less than ± 1,000 Volts within 12 inches of unprotected ESDS devices if those voltages are not controlled by other means. Suggested voltage limits: Other than room systems: < ± 50 V offset; room system: < ± 150 V offset.
7. ESD-Protected Area and Workstation Identification	ESD caution signs shall be posted at each ESD-protected workstation or at the entrances of defined ESD-protected areas.

2.3.1.3 Personnel Controls

To avoid ESD through human contact with sensitive devices during handling, personnel are required to apply proper protection practices. Personnel controls can be broken down into two areas:

- Protection – ESD-protective smocks should be worn both to shield ESDS devices from charges developed on operators' bodies and clothing and to dissipate any charges generated during the course of work. In addition, antistatic/conductive gloves or finger cots can be worn to provide an additional level of protection when handling every ESDS device. It is important to note that these measures apply not only to the individuals working the ESD-protected area, but also to anyone who enters the area.

- Grounding – The body must be grounded through a wrist strap to the workstation. Additional grounding may be used through either a heel strap or ESD-protective footwear, to the dissipative flooring. The wrist strap ties the body to the common ground at the workstation, and the heel strap/footwear helps dissipate any charges generated while moving through the ESD-protected area.

2.3.1.4 Equipment Controls

All equipment used in the ESD-protected area needs to be grounded and have its insulators removed. This includes all chairs, carts, solder stations, testers, handlers, etc. Any equipment purchased should be evaluated for its ESD performance. Chairs and carts should have conductive feet or casters to allow them to be grounded with the dissipative flooring. Other equipment that will handle ESDS devices must have all conductive surfaces grounded to prevent the buildup of charges.

2.3.1.5 Storage and Packaging

Any storage rack holding ESDS devices should be grounded. Any carrier used within the ESD-protected area as well as packaging material used to ship devices from one protected area to another should:

- Not generate any charges.
- Dissipate any generated charges.
- Shield from external charges, where possible.

2.3.1.6 Training and Maintenance

The effectiveness of an ESD-protected area will be negated if it is not regularly tested and maintained and if personnel are not trained. To maintain effectiveness, attention must be paid to the following three areas:

- Training – Any personnel who will be working on ESDS devices or doing maintenance work in facilities that are designated as ESD-protected areas must be ESD certified. ESD certification classes are offered through the NASA Manufacturing Technology Transfer Center (NMTTC), or another facility that is NASA certified to instruct in ESD protocols. Certification cards are valid for 2 years and should be accessible for QA auditors at all times. Personnel currently handling ESDS devices should attend regular refresher courses every 2 years.

- Testing – All ESD-protective items (wrist straps, work surfaces, etc.) in the ESD-protected area need to be tested on a regular basis to verify their correct operation.

- Maintenance – All equipment (e.g., ionizers, handlers, etc.) needs to be maintained on the vendor-recommended schedule to ensure not only proper operation but also effectiveness in preventing ESD events.

3. SUMMARY

Almost all electronic devices are subject to damage by an ESD event. Damage as a result of ESD is difficult to detect and may not manifest until after the device or assembly has been used by an end customer. As a result, inadequate and improper handling of ESDS devices and assemblies can cost projects millions of dollars each year in damaged components and nonfunctional circuit boards.

Establishing an ESD Control Plan, set forth by this document, will reduce the probability that an ESD event will occur on flight hardware in any of the testing or integration areas within EED. By training personnel on the precautions and handling of ESDS parts, and continual environmental monitoring and verification of ESD-protected work areas, damage to ESDS parts and assemblies will be reduced, thus saving projects time and money in rework efforts.

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7. NASA-STD-8739.7, Requirements for Electrostatic Discharge Control.

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9. Actel ESD Primer White Paper, March 2004.

APPENDIX A

OPERATION OF ESD

ESD can occur in a variety of forms. One of the most common is through human contact with sensitive devices. As the current dissipates through an object, it seeks a low-impedance path to ground to equalize potentials. In most cases, ESD currents will travel to ground via the metal chassis frame of a device. This current flow will burn holes invisible to the naked eye into an integrated circuit (IC), with evidence of heat damage to the surrounding area.

ESD DAMAGE

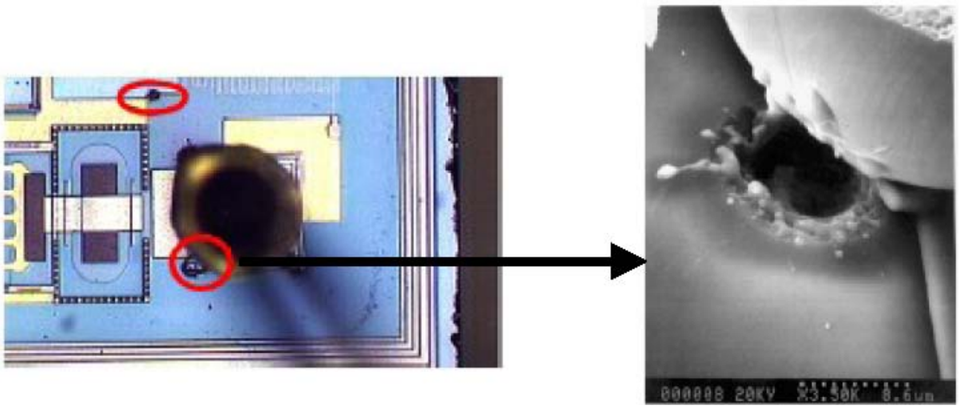
ESD damage is generally classified as either a catastrophic failure or a latent defect.

Catastrophic Failure

When an electronic device is exposed to an ESD event, it may no longer function. The ESD event may cause a metal melt, junction breakdown, or oxide failure. The device's circuitry can be permanently damaged, causing the device fail. Such failures usually can be detected when the device is tested before shipment. If the ESD event occurs after test, the damage will go undetected until the device fails in operation. [2], [3]

Latent Defects

Latent defects are more difficult to identify than any other type of failure. A device that is exposed to an ESD event may be partially degraded, yet continue to perform its intended function. However, the operating life of the device may be reduced significantly. A product or system incorporating devices with latent defects may experience premature failure after the user places them in service. Such failures are usually costly to repair and in some applications may create personnel hazards. Figures 1 and 2 show ESD damage on the input of a device during ESD simulation testing. [2], [3]



Figures 1 and 2. Visual ESD Damage of Ball Bond on Circuit Board
(Source: ADI Reliability Handbook)

FAILURE MECHANISMS OF PARTS

Three failure mechanisms for hard failures have been experimentally noted for semiconductor devices: thermal breakdown, dielectric breakdown, and metallization melt.

Thermal Breakdown

Thermal breakdown is caused by the injection of an electrical transient, such as an ESD pulse, of sufficient amplitude and duration to initiate a meltdown in a portion of the device junction. Large temperature change, short transient time of ESD pulse, and the lack of heat diffusion cause hot spots on the silicon and with enough energy to melt the silicon, short-circuiting the junction and failing the device.

Dielectric Breakdown

When the voltage across a dielectric region exceeds its dielectric tolerances, the result is a puncture of the dielectric. Once the dielectric has been punctured, a small amount of energy is enough to create a short circuit. After dielectric breakdown, the device will usually exhibit lower breakdown voltage or increased leakage current, but not a catastrophic failure.

Metallization Layer Melt

Failures can also occur when ESD transients increase the device temperature sufficiently to melt metal off of fuse bond wires. Metallization layer melt is considered a secondary failure mechanism. It occurs when a second dielectric breakdown results in a short circuit, which then draws enough current to melt the metallization layer.