DOD-HDBK-263 METRIC
2 May 1980

MILITARY HANDBOOK

ELECTROSTATIC DISCHARGE CONTROL HANDBOOK FOR PROTECTION OF ELECTRICAL AND ELECTRONIC PARTS, ASSEMBLIES AND EQUIPMENT (EXCLUDING ELECTRICALLY INITIATED EXPLOSIVE DEVICES)

METRIC

FSC RELI

DOD-HDBK-263
2 May 1980

DEPARTMENT OF DEFENSE
Washington, D.C. 20360

DOD-HDBK-263
Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically-Initiated Explosive Devices)

1. This standardization handbook was developed by the Department of the Navy, Naval Sea Systems Command.

2. This publication was approved 2 May 1980 for printing and inclusion in the military standardization handbook series.

3. This Handbook provides guidelines, not mandatory requirements, for the establishment and implementation of an Electrostatic Discharge (ESD) Control Program in accordance with DOD-STD-1686. This document is applicable to the protection of electrical and electronic parts from damage due to ESD and does not provide information for protection from inadvertent operation of electrically initiated explosive devices from an ESD.

4. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Naval Sea Systems Command, ATTN: Code 3112, Washington, D.C. 20362, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

1. In the past, various segments of industry have become aware of the damage static electricity can impose on metal oxide semiconductors (MOS) as evidenced by low production yields. Sensitivity of other parts to electrostatic discharge (ESD) has more recently become evident through use, testing, and failure analysis. Trends in technology are towards greater complexity, increased packaging density and hence thinner dielectrics between active elements which results in parts becoming even more sensitive to ESD. The construction and design features of current microtechnology have resulted in parts which can be destroyed or damaged by ESD voltages as low as 20 volts.

2. Various electrical and electronic parts which have been determined to be sensitive to electrostatic voltage levels commonly generated by production, test, operation, and maintenance personnel include: microelectronic and semiconductor devices; thick and thin film resistors, chips and hybrid devices; and piezoelectric crystals. Additionally, all subassemblies, assemblies and equipment containing these parts not having adequate protective circuitry are also ESD sensitive (ESDS). Materials which are prime generators of electrostatic voltages include common plastics such as polyethylene, vinyls, foam, polyurethane, synthetic textiles, fiberglass, glass, rubber, and numerous other commonly used materials. Actions which cause these and other materials to generate electrostatic voltages are the sliding, rubbing or separation of materials. Such movements can frequently result in electrostatic voltages of 15,000 volts.

3. Protection of electrical and electronic ESDS parts, assemblies and equipment, collectively referred to herein as items, can be provided through the implementation of low cost ESD controls, many of which have been used in the ordnance industry for decades. However, overall implementation of ESD controls is not uniform and is not being instituted at a satisfactory rate. Lack of implementation of controls has resulted in high repair costs, excessive equipment downtime, and has reduced mission effectiveness because susceptible parts are being damaged during processing, assembly, inspection, handling, packaging, shipping, storage, stowage, testing, installation and maintenance -- throughout the equipment life cycle, both at the manufacturer's and the user's facility.

4. The effects of ESD on electrical and electronic items are not generally recognized because they are often masked by reasons such as: (1) failures due to ESD are often analyzed as being caused by electrical overstress due to transients other than static; (2) failures caused by ESD are often incorrectly categorized as random, unknown, infant mortality, manufacturing defect, or other, due to improper depth of failure analysis; (3) few failure analysis laboratories are equipped with scanning electron microscopes or other equipment and technology required to trace failures to ESD; (4) some programs and projects are accepting high operational failure rates as normal and simply procuring more spares instead of recognizing and solving the basic ESD problem; (5) belief of personnel that static controls are necessary for only MOS at the part manufacturer's site and for handling of ordnance; (6) belief by many people that an ESDS part "protected" by a diode, resistive network or other protective part techniques is non-ESDS; (7) static discharge failures do not always occur immediately following exposure, but may result in latent defects.

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

TABLES

FIGURES

1. SCOPE. This handbook provides guidance for developing, implementing, and monitoring elements of an ESD control program including: identification of causes and effects of ESD on electrical and electronic parts, assemblies and equipment; development of ESD control program controls; selection and application considerations for ESD protective materials and equipment; design and construction of ESD protected areas and grounded work benches; the preparation of ESD operating, handling, packaging and marking procedures; development of ESD personnel training programs; and certification of ESD protected areas and grounded work benches.

2. REFERENCED DOCUMENTS

2.1 Issues of documents. The following documents of the issue in effect on date of invitation for bids or request for proposal form a part of this handbook to the extent specified herein:

SPECIFICATIONS

FEDERAL

PPP-C-1842	Cushioning Material, Plastic, Open Cell (for Packaging Application)

MILITARY

MIL-M-38510	Microcircuits, General Specifications for
MIL-B-81705	Barrier Materials, Flexible, Electrostatic-free, Heat Sealable
MIL-P-81997	Pouches, Cushioned, Flexible, Electrostatic-free, Recloseable, Transparent
MIL-P-82646	Plastic Film, Conductive, Heat Sealable, Flexible
MIL-B-82647	Bags, Conductive Plastic, Heat Sealable, Flexible

STANDARDS

FEDERAL

FED-STD-101	Federal Test Method Standard

MILITARY

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-454	Standard, General Requirements for Electronic Equipment
MIL-STD-701	Lists of Standard Semiconductor Devices

STANDARDS

MILITARY (Continued)

DOD-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically-Initiated Explosive Devices)

(Copies of specifications, standards, drawings and publications required by contractors in connection with specific procurements should be obtained from the acquiring activity or as directed by the contracting officer).

2.2 Other publications. The following documents form a part of this handbook to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

CODE OF FEDERAL REGULATIONS

CFR, Title 29, Part 1900 to 1919, Chapter XVII	Code of Federal Regulations, Occupational Safety and Health Administration, Department of Labor

AMERICAN SOCIETY OF TESTING AND MATERIALS

ASTM D257	D-C Resistance or Conductance of Insulating Materials
ADTM D991	Volume Resistivity of Electrically Conductive and Antistatic Elastomers

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103).

3. DEFINITIONS. The following definitions apply. Definitions in referenced documents apply to the extent they do not conflict with definitions provided herein.

3.1 Anti-static material. ESD protective material having a surface resistivity greater than 10^9 but not greater than 10^{14} ohms per square.

3.2 Conductive material. ESD protective material having a surface resistivity of 10^5 ohms per square maximum.

3.3 Decay time. The time for a static charge to be reduced to a given percent of the charge's peak voltage.

3.4 Electrical and electronic part. A part such as a microcircuit, discrete semiconductor, resistor, capacitor, thick or thin film device, or piezoelectric crystal.

3.5 Electrostatic Discharge (ESD). A transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field.

3.6 ESD protective material. Material capable of one or more of the following: limiting the generation of static electricity, rapidly dissipating electrostatic charges over its surface or volume, or providing shielding from ESD spark discharge or electrostatic fields. ESD protective materials are classified in accordance with their surface resistivity (or alternate conductivity) as conductive, static dissipative or antistatic.

3.7 ESD protective packaging. Packaging with ESD protective materials to prevent ESD damage to ESDS items.

3.8 ESD sensitive (ESDS) items. Electrical and electronic parts, assemblies and equipment that are sensitive to ESD voltages of 15,000 volts or less as determined by the test circuit of figure 1. ESDS items are classified as:

a. Class 1: Those sensitive to voltages of 1,000 volts or less;

b. Class 2: Those sensitive to voltages greater than 1,000 volts but less than or equal to 4,000 volts;

c. Class 3: Those sensitive to voltages greater than 4,000 volts but less than or equal to 15,000 volts.

3.9 Electrostatic field. A voltage gradient between an electrostatically charged surface and another surface of a different electrostatic potential.

3.10 Ground. A mass such as earth, a ship or vehicle hull, capable of supplying or accepting large electrical charge.

3.11 Hard ground. A connection to ground either directly or through a low impedance.

3.12 Handled or handling. Actions in which items are hand manipulated or machine processed during actions such as inspections, manufacturing, assembling, processing, testing, repairing, reworking, maintaining, installing, transporting, failure analysis, wrapping, packaging, marking or labeling.

3.13 Insulative material. Material having surface resistivities greater than 10^{14} ohms per square.

3.14 Protected area. An area which is constructed and equipped with the necessary ESD protective materials and equipment to limit ESD voltage below the sensitivity level of ESDS item handled therein.

3.15 Protective handling. Handling of ESDS items in a manner to prevent damage from ESD.

3.16 Soft ground. A connection to ground through an impedance sufficiently high to limit current flow to safe levels for personnel (normally 5 milliamperes). Impedance needed for a soft ground is dependent upon the voltage levels which could be contacted by personnel near the ground.

3.17 Static dissipative materials. ESD protective materials having surface resistivities greater than 10^5 but not greater than 10^9 ohms per square.

3.18 Surface resistivity (ρs). The surface resistivity is an inverse measure of the conductivity of a material and equal to the ratio of the potential gradient to the current per unit width of the surface, where the potential gradient is measured in the direction of current flow in the material.

(Note: Surface resistivity of a material is numerically equal to the surface resistance between two electrodes forming opposite sides of a square. The size of the square is immaterial. Surface resistivity applies to both surface and volume conductive materials and has the value of ohms per square).

3.19 Volume resistivity (ρv). The volume resistivity is an inverse measure of the conductivity of a material and is equal to the ratio of the potential gradient to the current density, where the potential gradient is measured in the direction of current flow in the material.

(Note: In the metric system, volume resistivity of an electrical insulating material in ohm-cm is numerically equal to the volume resistance in ohms between opposite faces of a 1cm cube of the material. Volume resistivity in Ω-m has a value of 0.01 the value in Ω-cm).

4. CAUSES AND EFFECTS OF STATIC ELECTRICITY

4.1 Nature of static electricity. Static electricity is electrical charge at rest. The electrical charge is due to the transfer of electrons within a body (polarization) or from one body to another (conductive charging). The transfer occurs due to interaction of charged bodies or charged and uncharged bodies. The magnitude of the charge is primarily dependent on the size, shape, composition and electrical properties of the substances which make up the bodies. Some substances readily give up electrons while others tend to accumulate excess electrons. A body having an excess of electrons is charged negatively; a body having an electron deficit is charged positively. When two substances are rubbed together, are separated, or flow relative to one another (such as a gas or liquid over a solid), one substance gains electrons and the other loses electrons. These electron charges are equal and in the case of nonconductors tend to remain in the localized area of contact; charges on conductors, however, are rapidly distributed over its surface and the surfaces of other conductive objects which it contacts. An electrostatic field or lines of force exist between a charged body and a body at a different electrostatic potential, such as a body with more or less electron charges. Conductive and insulative bodies that enter this field will be polarized by induction (that is, without contacting the charged body). In a conductive body, electrons closest to the more negative part of the field are repelled, leaving that area relatively positively charged, and are attracted to the more positive part of the field creating negatively and positively charged areas although the net charge on the body will remain zero. If a conductive polarized body is subsequently grounded, electrons will flow to or from the polarized surface near the ground and the body itself becomes charged by accumulating an excess or deficit of electrons. In a non-conductive body electrons are less mobile, but dipoles tend to align with the field creating apparent surface charges. A non-conductor cannot be inductively charged.

4.1.1 The capacitance of a charged body relative to another body or ground also has an effect on the electrostatic field. When capacitance is reduced for a given charge (Q) there is an inverse linear increase in voltage based on the relationship, $Q = CV$, where C is the capacitance and V is the voltage. As the capacitance is continually decreased the voltage will increase until a discharge occurs via an arc. For example, when common polyethylene bags are rubbed, the charge potential may be only a few hundred volts while lying on a bench, but when picked up by an operator, may be several thousand volts due to the decrease in capacitance.

4.2 Triboelectric series. The generation of static electricity caused by rubbing two substances is called the triboelectric effect. A triboelectric series is a list of substances in an order of positive to negative charging as a result of the triboelectric effect. A substance higher on the list is positively charged when rubbed with a substance lower on the list due to the fact that substances higher on the list have more free electrons compared to substances lower on the list. Electrons from substances higher on the list are therefore transferred to substances lower on the list. However, the order of ranking in a triboelectric series is not always a constant or repetitive. Furthermore, the degree of separation of two substances in the triboelectric series does not necessarily indicate the magnitude of the charges created by triboelectric effect. Order in the series and magnitude of the charges are dependent upon the properties or nature of the substance, but these properties are modified by factors such as surface cleanliness, ambient conditions, pressure of contact, speed of rubbing or separation, lubricity and the amount of surface area over which the rubbing occurs. A sample triboelectric series is provided in table I. In addition to actual rubbing two different substances, substantial electrostatic charges can also be generated triboelectrically when two pieces of the same material, especially common plastic, in intimate contact, are separated as occurs when separating the sides of a plastic bag.

4.3 Prime sources of static electricity. Typical prime charge sources commonly encountered in a manufacturing facility are listed in table II. These prime sources are essentially insulators and are typically synthetic materials. Electrostatic voltage levels generated with these insulators can be extremely high since they are not readily distributed

TABLE I. Sample triboelectric series

Positive +	Air
	Human Hands
	Asbestos
	Rabbit Fur
	Glass
	Mica
	Human Hair
	Nylon
	Wool
	Fur
	Lead
	Silk
	Aluminum
	Paper
	Cotton
	Steel
	Wood
	Amber
	Sealing Wax
	Hard Rubber
	Nickel, Copper
	Brass, Silver
	Gold, Platinum
	Sulfur
	Acetate Rayon
	Polyester
	Celluloid
	Orlon
	Polyurethane
	Polyethylene
	Polypropylene
	PVC (Vinyl)
	KEL F
	Silicon
Negative -	Teflon

TABLE II. Typical prime charge sources

Object or Process	Material or Activity
Work Surfaces	• Waxed, painted or varnished surfaces • Common vinyl or plastics
Floors	• Sealed concrete • Waxed, finished wood • Common vinyl tile or sheeting
Clothes	• Common clean room smocks • Common synthetic personnel garments • Non-conductive shoes • Virgin cotton 1/
Chairs	• Finished wood • Vinyl • Fiberglass
Packaging and Handling	• Common plastic - bags, wraps, envelopes • Common bubble pack, foam • Common plastic trays, plastic tote boxes, vials, parts bins
Assembly, Cleaning, Test and Repair Areas	• Spray cleaners • Common plastic solder suckers • Solder irons with ungrounded tips • Solvent brushes (synthetic bristles) • Cleaning or drying by fluid or evaporation • Temperature chambers • Cryogenic sprays • Heat guns and blowers • Sand blasting • Electrostatic copiers

1/ Virgin cotton can be a static source at low relative humidities such as below 30 percent.

over the entire surface of the substance or conducted to another contacting substance. The conductivity of some insulative materials is increased by absorption of moisture under high humidity conditions onto the otherwise insulating surface, creating a slightly conductive sweat layer which tends to dissipate static charges over the material surface. The generation of 15,000 volts from common plastics in a typical manufacturing facility is not unusual. Table III shows typical electrostatic voltages generated by personnel in a manufacturing facility.

5. SUSCEPTIBILITY OF ITEMS TO ESD. Numerous parts are susceptible to damage when an ESD occurs across their terminal or when these parts are exposed to electrostatic fields. ESDS parts can be destroyed by an ESD where one pin is connected to a high voltage source and other pins are ungrounded. In other words, a hard ground connection is not required to destroy an ESDS part. MOS large scale integration devices in hermetic packages with non-conductive lids could be damaged by spraying the lid with canned coolant despite there being no ground path connected to the part. ESDS parts installed in assemblies normally have their leads connected to a sufficient mass of conductive material such as printed wiring board (PWB) runs and wiring which may provide the required ground to result in damage from an ESD. In such cases, however, the voltages required are normally higher than those needed when one or more pins or the part case is grounded. Parts susceptible to ESD include: microelectronic devices; discrete semiconductors, film resistors, resistor chips, other thick and thin film devices; and piezoelectric crystals. Known ESDS part types and their relative sensitivities are listed in Table IV. Table IV part sensitivity is based upon a 100 pF, 1,500 ohm test circuit applying one discharge pulse. These sensitivity leads will vary for different test circuits and generally will be substantially less where multiple discharge pulses are applied.

Assemblies and equipment containing ESDS parts are often as sensitive as the most sensitive ESDS part which they contain. Incorporation of protective circuitry in these assemblies and equipment can provide varying degrees of protection from ESD applied to their terminals. Such assemblies and equipment, however, can still be vulnerable from induced ESDs caused by strong electrostatic fields or by contact of PWB electrical connections or paths with a charged object.

5.1 Types of ESD failure. ESD can cause intermittent or upset failures as well as hard failures of electronics. Intermittent or upset failures can occur on certain types of parts such as LSI memories and on chips, either prior to or after lidding and sealing. Such failures can also occur when equipment is in operation and is usually characterized by a loss of information or temporary distortion of its functions. No apparent hardware damage occurs and proper operation resumes automatically after the ESD exposure or in the case of some digital equipment, after re-entry of the information by re-sequencing the equipment.

5.1.1 Upset can be the result of an ESD spark in the vicinity of the equipment. The electromagnetic pulse (EMP) generated by the spark causes erroneous signals to be picked up by the equipment circuitry. Upset can also occur by the capacitive or inductive coupling of an ESD pulse or by the direct discharge of an ESD through a signal path providing an erroneous signal.

TABLE III. Typical electrostatic voltages

Means of Static Generation	Electrostatic Voltages	
	10 to 20 Percent Relative Humidity	65 to 90 Percent Relative Humidity
Walking across carpet	35,000	1,500
Walking over vinyl floor	12,000	250
Worker at bench	6,000	100
Vinyl envelopes for work instructions	7,000	600
Common poly bag picked up from bench	20,000	1,200
Work chair padded with poly-urethane foam	18,000	1,500

TABLE IV. List of ESDS parts by part type

CLASS 1: SENSITIVITY RANGE 0 TO $\le$1000 VOLTS

- Metal Oxide Semiconductor (MOS) devices including C, D, N, P, V and other MOS technology without protective circuitry, or protective circuitry having Class 1 sensitivity
- Surface Acoustic Wave (SAW) devices
- Operational Amplifiers (OP AMP) with unprotected MOS capacitors
- Junction Field Effect Transistors (JFETs) (Ref.: Similarity to MIL-STD-701: Junction field effect, transistors and junction field effect transistors, dual unitized)
- Silicon Controlled Rectifiers (SCRs) with Io<0.175 amperes at 100° Celsius ($^{\circ}$C) ambient temperature (Ref.: Similiarity to MIL-STD-701: Thyristors (silicon controlled rectifiers))
- Precision Voltage Regulator Microcircuits: Line or Load Voltage Regulation <0.5 percent
- Microwave and Ultra-High Frequency Semiconductors and Microcircuits: Frequency >1 gigahertz
- Thin Film Resistors (Type RN) with tolerance of $\le$ 0.1 percent;power >0.05 watt
- Thin Film Resistors (Type RN) with tolerance of > 0.1 percent;power $\le$0.05 watt
- Large Scale Integrated (LSI) Microcircuits including microprocessors and memories without protective circuitry, or protective circuitry having Class 1 sensitivity (Note: LSI devices usually have two to three layers of circuitry with metallization crossovers and small geometry active elements)
- Hybrids utilizing Class 1 parts

CLASS 2: SENSITIVITY RANGE >1000 TO $\le$4000 VOLTS

- MOS devices or devices containing MOS constituents including C, D, N, P, V, or other MOS technology with protective circuitry having Class 2 sensitivity
- Schottky diodes (Ref.: Similiarity to MIL-STD-701: Silicon switching diodes (listed in order of increasing trr))
- Precision Resistor Networks (Type RZ)
- High Speed Emitter Coupled Logic (ECL) Microcircuits with propagation delay $\le$1 nanosecond
- Transistor-Transistor Logic (TTL) Microcircuits (Schottky, low power, high speed, and standard)
- Operational Amplifiers (OP AMP) with MOS capacitors with protective circuitry having Class 2 sensitivity
- LSI with input protection having Class 2 sensitivity
- Hybrids utilizing Class 2 parts

TABLE IV. List of ESDS parts by part type (Cont'd)

CLASS 3: SENSITIVITY RANGE >4000 TO $\leq$15,000 VOLTS
• Lower Power Chopper Resistors (Ref.: Similarity to MIL-STD-701: Silicon Low Power Chopper Transistors)
• Resistor Chips
• Small Signal Diodes with power $\leq$ 1 watt excluding Zeners (Ref.: Similarity to MIL-STD-701: Silicon Switching Diodes (listed in order of increasing trr))
• General Purpose Silicon Rectifier Diodes and Fast Recovery Diodes (Ref.: Similarity to MIL-STD-701: Silicon Axial Lead Power Rectifiers, Silicon Power Diodes (listed in order of maximum DC output current), Fast Recovery Diodes (listed in order of trr))
• Low Power Silicon Transistors with power $\leq$5 watts at 25°C (Ref.: Similarity to MIL-STD-701: Silicon Switching Diodes (listed in order of increasing trr), Thyristors (bi-directional triodes), Silicon PNP Low-Power Transistors (Pc $\leq$5 watts @T_A = 25°C), Silicon RF Transistors)
• All other Microcircuits not included in Class 1 or Class 2
• Piezoelectric Crystals
• Hybrids utilizing Class 3 parts

5.1.2 While upset failues occur when the equipment is operating, catastrophic failures can occur any time. Catastrophic ESD failures can be the result of electrical overstress of electronic parts caused by an ESD such as: a discharge from a person or object, an electrostatic field, or a high voltage spark discharge. Some catastrophic failures may not occur until some time after exposure to an ESD as in the case of marginally damaged ESDS parts which require operating stress and time to cause further degradation and ultimate catastrophic failure. Only certain part types seem to be susceptible to this latent failure process. There are some types of catastrophic ESD failures which could be mistaken for upset failures. For example, an ESD could result in aluminum shorting through a SiO_2 dielectric layer. Subsequent high currents flowing through the short, however, could vaporize the aluminum and open the short. This failure may be confused with upset failure if it occurs during equipment operation, but the damage due to the ESD would be a latent defect that will probably reduce the operating life of the part.

5.2 Part upset. Parts that are very susceptible to ESD upset are any logic family that require small energies to switch states or small changes of voltage in high impedance lines. Examples of families that are sensitive would be NMOS, PMOS, CMOS and low power TTL. Linear circuits with high impedance, and high gain inputs would also be highly susceptible along with RF amplifiers and other RF parts at the equipment level, however, design for RFI immunity can protect these parts from damage due to ESD high voltage spark discharge. To protect parts sensitive to ESD high spark discharge at the equipment level requires: good RFI/EMC design, buffering of busses, proper termination of busses, shielding of bus conductors and the avoidance of penetrations of the equipment cabinet that lead to sensitive parts.

5.3 Failure mechanisms. ESD related failure mechanisms typically include:

a. Thermal secondary breakdown
b. Metallization melt
c. Dielectric breakdown
d. Gaseous arc discharge
e. Surface breakdown
f. Bulk breakdown

The failure mechanisms of a, b, and f are power dependent while failure mechanisms c, d, and e are voltage dependent. All the above failure mechanisms are applicable to microelectronic and semiconductor devices. Failure mechanisms b or d have been evident in film resistors; failure mechanism f in piezoelectric crystals. Besides these catastrophic failure mechanisms, unencapsulated chips and LSI MOS integrated circuits have exhibited temporary failure due to failure mechanisms d from positive charges deposited on the chip as a by-product of gaseous arc discharge within the package between the lid and the substrate.

5.3.1 Thermal secondary breakdown. Thermal secondary breakdown is also known as avalanche degradation. Since thermal time constants of semiconductor materials are generally large compared with transient times associated with ESD pulse, there is little diffusion of heat from the areas of power dissipation and large temperature gradients can form in the parts.

Localized junction temperatures can approach material melt temperatures, usually resulting in development of hot spots and subsequent junction shorts due to melting. This phenomenon is termed thermal secondary breakdown. For junction melting to occur in Bipolar (P-N) junctions, sufficient power must be dissipated in the junction. In the reverse bias condition, most of the applied power is absorbed in the immediate junction area with minimal power loss in the body of the part. In the forward bias condition, the junction exhibits lower resistance. Even though a greater current flows, a greater percentage of the power is dissipated in the body of the part. Thus more power is generally required for junction failure in the forward bias condition. For most transistors, the emitter-base junction degrades with lower current values than collector-base junction. This is because the emitter-base junction normally has smaller dimensions than any of the other junctions in the circuit. For reversed polarity signals, only a very small microampere current flows until the voltage exceeds the breakdown voltage of the junction. At breakdown, the current increases and results in junction heating due to the nucleation of hot spots and current concentrations. At the point of second breakdown, the current increases rapidly due to a decrease in resistivity and a melt channel forms that destroys the junction. This junction failure mode is a power dependent process.

5.3.2 Metallization melt. Failures can also occur when ESD transients increase part temperature sufficiently to melt metal or fuse bond wires. Theoretical models exist which allow computation of currents causing failure for various materials as a function of area and current duration. Such models are based on the assumption of uniform area of the interconnection material. In practice, it is difficult to maintain a uniform area, the resultant non-uniform area can result in localized current crowding and subsequent hot spots in the metallization. This type of failure could occur where the metal strips have reduced cross-sections as they cross oxide steps. Normally due to shunting of the currents by the junction, this failure requires an order of magnitude larger power level at higher frequencies than is required for junction damage at lower frequencies. Below 200 to 500 megahertz the junction capacitance still presents a high impedance to currents, shunting them around the junction.

5.3.3 Dielectric breakdown. When a potential difference is applied across a dielectric region in excess of the region's inherent breakdown characteristics, a puncture of the dielectric occurs. This form of failure is due to voltage rather than power and could result in either total or limited degradation of the part depending on the pulse energy. For example, the part may heal from a voltage puncture if the energy in the pulse is insufficient to cause fusing of the electrode material in the puncture. It will, however, usually exhibit lower breakdown voltage or increased leakage current after such an event, but not catastrophic part failure. This type of failure could result in a latent defect resulting in catastrophic failure with continued use. The breakdown voltage of an insulating layer is a function of the pulse rise time since time is required for avalanching of the insulating material.

5.3.4 Gaseous arc discharge. For parts with closely spaced unpassivated-thin electrodes, gaseous arc discharge can cause degraded performance. The arc discharge condition causes vaporization and metal movement which is generally away from the space between the electrodes. The melting and fusing do not move the thin metal into the interelectrode regions. In melting and fusing, the metal pulls together and flows or opens along the electrode lines. There can be fine metal globules in the gap region, but not in sufficient numbers to cause bridging. Shorting is not considered a major problem with unpassivated thin metal electrodes. On a surface acoustic wave (SAW) band pass filter device with thin metal of approximately 4,000 angstroms (Å) and 3.0 micrometers (μm) electrode spacing operational degradation was experienced from ESD.

5.3.4.1 When employing thicker metallization such as 13,500 Å, this gaseous arc discharge in an arc gap at typically 50 μm can be used for protection to dissipate incoming high voltage spikes.

5.3.4.2 For LSI and memory ICs with passivation/active jucntion interfaces susceptible to inversion, gaseous arc discharge from inside the package can cause positive ions to be deposited on the chip and cause failure from surface inversion. This has been reported to occur especially on parts with non-conducting lids. A special case of this is UVEPROMs with quartz lids where failures can be annealed by neutralizing the positive charge with ultra violet light through the quartz lid.

5.3.5 Surface breakdown. For perpendicular junctions the surface breakdown is explained as a localized avalanche multiplication process caused by narrowing of the junction space charge layer at the surface. Since surface breakdown depends on numerous variables, such as geometry, doping level, lattice discontinuities, or unclean gradients, the transient power which can be dissipated during surface breakdown is generally unpredictable. The destruction mechanism of surface breakdown results in a high leakage path around the junction, thus nullifying the junction action. This effect, as well as most voltage sensitive effects like dielectric breakdown, is dependent upon the rise time of the pulse and usually occurs when the voltage threshhold for surface breakdown is exceeded before thermal failure can occur. Another mode of surface failure is the occurrence of an arc around the insulating material which is similar to metallization to metallization gaseous discharge except in this case discharge is between metallization and semiconductor.

5.3.6 Bulk breakdown. Bulk breakdown results from changes in junction parameters due to high local temperatures within the junction area. Such high temperatures result in metallization alloying or impurity diffusion resulting in drastic changes in junction parameters. The usual result is the formation of a resistance path across the junction. This effect is usually preceded by thermal secondary breakdown.

5.4 Part constituents susceptible to ESD. Different parts are susceptible to ESD in various degrees. These variations are due to different part designs and different constituents that go into making the part. Table V is a summary of constituents that are incorporated into various parts which are sensitive to ESD. Table V also lists the part types in which some of these constituents are found and the associated failure processes involved.

TABLE V. Part constituents susceptible to ESD

Part Constituent	Part Type	Failure Mechanism	Failure Indicator
MOS Structures	MOS FET (Discretes) MOS ICs Semiconductors with metalization cross-overs Digital ICs (Bipolar and MOS) Linear ICs (Bipolar and MOS) MOS Capacitors Hybrids Linear ICs	Dielectric breakdown from excess voltage and subsequent high current	Short (high leakage)
Semiconductor Junctions	Diodes (PN, PIN, Schottky) Transistors, Bipolar Junction Field Effect Transistors Thyristors Bipolar ICs, Digital and Linear Input Protection Circuits on: Discrete MOS FETs MOS ICs	Microdiffusion from microplasma-secondary breakdown from excess energy or heat Current filament growth by silicon and aluminum diffusion (electromigration)	

(Continued)

TABLE V. Part constituents susceptible to ESD (Cont'd)

Part Constituent	Part Type	Failure Mechanism	Failure Indicator
Film Resistors	Hybrid ICs: Thick Film Resistors Thin Film Resistors Monolithic IC-Thin Film Resistors Encapsulated Film Resistors	Dielectric breakdown, voltage dependent-creation of new current paths Joule heating-energy dependent-destruction of minute current paths	Resistance shift
Metallization Strips	Hybrid ICs Monolithic ICs Multiple Finger Overlay Transistors	Joule heating-energy dependent metallization burnout	Open
Field Effect Structures and Nonconductive Lids	LSI and Memory ICs employing nonconductive quartz or ceramic package lids especially ultraviolet EPROMS	Surface inversion or gate threshhold voltages shifts from ions deposited on surface from ESD	Operational degradation
Piezoelectric Crystals	Crystal Oscillators Surface Acoustic Wave Devices	Crystal fracture from mechanical forces when excessive voltage is applied	Operational degradation
Closely Spaced Electrodes	Surface Acoustic Wave Devices Thin metal unpassivated, unprotected semiconductors and microcircuits	Arc discharge melting and fusing of electrode metal	Operational degradation

5.4.1 MOS structures. A MOS structure is a conductor and a semiconductor substrate separated by a thin dielectric. Thus the acronyn MOS for metal-oxide-semiconductor is derived. A more general acronyn for this structure is MIS for metal-insulator-semiconductor. Dual dielectric systems such as MNOS (metal-nitride-oxide-semiconductor) are included in this susceptible constutuent classification.

5.4.1.1 Part types. Integrated circuits MOS technologies are NMOS (N-channel MOS), PMOS (P-channel MOS) and CMOS (Complementary MOS). Variations on these technologies are metal gate, silicon gate and silicon on sapphire. Difference in the susceptibility of these MOS technologies are dependent on the oxide or oxide-nitride gate dielectric breakdown and input protection circuitry to the external connections. The breakdown of the gate dielectric is mostly dependent on its thickness. Typically this has been 1100Å and with a dielectric strength ranging from $1x10^6$ volts per centimeter (V/cm) to $1x10^7$ V/cm. This results in breakdowns between 80 and 100 volts. Newer technology variations, however, like VMOS (vertical groove MOS) which has a higher field intensity at the end of the groove and HMOS (high density MOS) which has thinner gate dielectric have much lower breakdowns (25 to 80V) and therefore require more care in the design of the input protection circuitry.

5.4.1.1.1 Certain bipolar linear integrated circuit operation amplifiers incorporate capacitors on their monolithic chip. These capacitors are MOS structures and are susceptible to dielectric breakdown from ESD. Those operational amplifiers such as the 741 whose capacitors do not have apparent direct contact to external pins are less vulnerable than parts such as the HA2520 whose capacitors are placed directly across an external pin combination.

5.4.1.1.2 Hybrid circuits can incorporate a chip capacitor which is a MOS structure with a dielectric vulnerable to ESD. MOS chip capacitors should not be used in hybrids since other chip capacitors are available which are not considered sensitive to ESD.

5.4.1.1.3 Many monolithic integrated circuits have metallization runs which cross-over active semiconductor region or low resistivity semiconductor regions with field oxide between them serving as the insulator. These are sometimes referred to as parasitic MOS transistors. Typically field oxide is 15,000Å thick with breakdowns around 1,000 volts, but when oxide is etched away for diffusion, subsequent growth of oxide before metallization may be less than 3,000Å. In this case, breakdown could occur at 100 volts because of field intensification at the bottom corners of the metallization step and weak dielectric strength at the thin-thick oxide interface. When external pins are directly connected to such metallization runs, susceptibility to ESD occurs.

5.4.1.2 Failure mechanisms. ESD can damage the oxide in MOS structures because their breakdown voltage is low in comparison to voltage levels encountered with ESD. Breakdown of the oxide insulator results in permanent damage as opposed to breakdown of a semiconductor which is reversible. For very short duration over-voltages, some lattice damage might occur such that subsequent breakdown and therefore avalanche occurs at a lower value than the initial breakdown.

5.4.1.3 Failure indicators. As the punch-through short occurs the metallization will flow through the dielectric to create a low resistance short. However, in some instances where there is particularly thin metallization such as 4,000Å, or there is sufficient energy passed through the short, the metal will be vaporized and the short will clear but leave a cratered hole in the dielectric. Degraded performance may result but not a catastrophic failure. There is conjecture that the short in some circumstances might reappear or performance might continue to degrade.

5.4.2 Semiconductor junctions. Included in this constituent classification are PN junctions, PIN junctions and Schottky barrier junctions. Their sensitivity to ESD depends on geometry, size, resistivity, impurities, junction capacitance, thermal impedance, reverse leakage current and reverse breakdown voltage. The energy required to damage a junction in the forward biased direction is generally ten times that required in the reversed bias direction. Junctions with high breakdown voltage of greater than 100 volts and low leakage currents of less than 1 nanosecond are generally more susceptible to ESD than junctions of comparable size with low breakdown, such as 30 volts leakage greater than 1 microampere.

5.4.2.1 Part types. The emitter-base junctions in bipolar transistors whether integrated circuit or a discrete transistor are usually more susceptible to ESD damage than collector-base or collector-emitter junctions. This is primarily due to size and geometry where the emitter-side wall experiences large energy densities during reverse biased ESD. Because of larger areas the collector-base and collector-emitter do not experience the same energy densities, although with the collector-base and collector-emitter it is possible to laterally forward bias the base-emitter in which case a current crowding at the emitter side wall will occur.

5.4.2.1.1 Junction field effect transistors which have high impedance gates are particularly sensitive to ESD. They have extremely low gate to drain and gate to source leakage in the order of less than 1 nanoampere and relatively high breakdown voltage of greater than 50 volts. Therefore the gate to drain and gate to source are usually the most sensitive ESD paths.

5.4.2.1.2 Schottky barrier junctions such as the 1N5711 diode and TTL Schottky integrated circuits are particularly sensitive to ESD because they have very thin junctions and the presence of metal which may be carried through the junction.

5.4.2.1.3 Not all diodes, transistors and thyristors contain semiconductor junctions that are considered sensitive to ESD. Transient suppressor diodes, zener diodes, power rectifiers, power transistors and power thyristors have been found to be insensitive to ESD. Semiconductor junctions as sensitive ESD constituents are found not only in diodes, transistors, and bipolar integrated circuits but also in MOS as parasitic diodes and input protection clamps. Although the input parts protection junctions are meant to provide protection from ESD damage, the size of the protective junctions are limited due to cost and performance tradeoffs. Thus ESD pulses of sufficient energy can damage the input protection junctions.

5.4.2.2 Failure mechanisms. The temperature coefficient of extrinsic semiconductors is positive. That is, the higher the temperature, the higher the resistance. This feature prevents current crowding and hot spots from forming at low temperatures. However, in the reverse biased mode all the energy is being dissipated by the relatively large voltage drop across the relatively narrow depletion width of the junction. Due to geometry effects, local resistance variations, and crystal defects, perfectly uniform current distribution does not occur across the junction. As an ESD occurs across the junction the temperature at the depletion region increases quickly and the extrinsic semiconducting material becomes an intrinsic semiconducting material, causing a sharp decrease in resistance, resulting in thermal secondary breakdown.

5.4.2.2.1 The more rapid the discharge, the more uniform is the increase in temperature and therefore current across the junction. This means that for short duration discharges of less than 10 nanoseconds the resultant filament short is wide compared to longer duration discharges. It is possible for spots to develop but not grow completely across the junction such that at low bias voltages they do not cause a failure condition. However, during operation at certain bias conditions locally high current densities may exist with a corresponding highly localized large increase in temperature at the previously formed hot spot locations such that continued growth of a filament short may occur or silicon and metallization may diffuse through the junction via the electromigration process at temperatures greater than 200 °C.

5.4.2.2.2 The low leakage high breakdown JFET and Schottky barrier junctions seem to be particularly susceptible to this failure process. It is this same failure process that requires the breakdown test on JFETs be performed as a leakage test rather than put the junction into breakdown. With low leakage junctions, highly localized currents can occur during junction reverse breakdown. With Schottky barrier junction metallization is immediately available to migrate through the junction at localized hot spots.

5.4.2.3 Failure indicators. As the current filament develops across a semiconductor junction it is analogous to putting a parallel resistor across the junction of the same value as the short. However, in some marginally formed hot spots it may be similar to putting a zener diode and a resistor in parallel with the junction. High leakage will be the failure indicator description when the filaments short is a high resistance short.

5.4.3 Film resistors. Resistor material adhering to an insulating substrate comes under the ESDS constituent classification of film resistor. The degree of sensitivity will depend on the ingredients and formulation of the resistor material and size-power considerations.

5.4.3.1 Part types. Hybrid microcircuits frequently contain either thin film resistors or thick film resistors. Hybrid designs which cannot tolerate large changes in resistance such as precision voltage regulators are sensitive to ESD. Thick film resistors consist of: a conductive metal oxide as the resistive element; a metal additive to improve electrical performance; and a glass frit to provide a support matrix, adhesion to the substrate, and resistivity control. Such parts are particularly sensitive to ESD. Since the change is almost always negative for thick films, electric discharge has been considered as a possible trimming method when conventional trimming overshoots the desired resistance tolerance. It has also been found that the thick film resistance changes are heavily dependent on voltage rather than energy.

5.4.3.1.1 Thin film resistors, on the other hand, are more energy dependent and do not have changes greater than 5 percent in resistance until the energy of discharge is sufficient to cause film rupture. In addition to hybrid microcircuits, some monolithic integrated circuits may also contain encapsulated thin film resistors, such as polysilicon resistors, as part of an input protection circuit.

5.4.3.1.2 Discrete encapsulated resistors which contain the film resistor structure are also sensitive to ESD. Carbon film, metal oxide, and metal film resistors are somewhat sensitive to ESD, especially at low tolerance and low wattage ratings. A frequent occurring ESD problem with resistors is with the 0.05 watt metal film, part RNC50, specified at 0.1 percent tolerance. Putting these parts in a polyethylene bag and rubbing them on another bag is sufficient to shift the tolerance of these resistors.

5.4.3.2 Failure mechanisms. The ESD failure mechanisms of film resistors are not well defined. This is partly the result of not knowing the ingredients and formulations of the resistor material which are often held proprietary by the manufacturer.

5.4.3.2.1 For thick film resistors the failure mechanism has been modeled as the creation of new shunt paths in a matrix of series-parallel resistors and infinitesimal capacitors isolating metallic islands. With the application of high electric fields the dielectric breakdown of the glass frit or other isolating dielectric material is exceeded and the ensuring rupture welds metallic particles together in a conducting path known as metallization melt. Since this model involves a dielectric breakdown process it is mostly voltage dependent.

5.4.3.2.2 It appears that the ESD behavior of resistive materials is very much a function of the number of parallel current paths or the number of capacitive couplings between parallel paths in the film structure. The nature of the glass used in the material also appears to be quite important, both because it influences the distribution of the resistive elements and because it can act itself as a resistive element. Thus the behavior of different thick film resistor paths to ESD can vary greatly. ESD sensitivity testing, therefore, should be specified for critical tolerance thick film resistors.

5.4.3.2.3 For thin film resistors and encapsulated metal film, metal oxide and carbon film resistors, the failure mechanism is primarily a thermal, energy dependent process modeled as the destruction of minute shunt paths. This mechanism is associated with an increasing resistance. At a lower ESD voltage, there is some small negative resistance shift on the thin film and metal film type resistor which appears to be voltage dependent. This negative shift is usually not more than 5 percent and is typically less than 1 percent before changing to positive shifts as ESD voltage increases.

5.4.3.3 Failure indicators. Some thin film resistors such as deposited tantalum nitride on SiO_2 substrates, may be so small and power limited that ESD voltages greater than 5,000 volts from a person can melt the resistor open. For most cases, however, a shift in resistance will be the failure indicator. Thus for circuit designs tolerant of large resistance changes, the failure may not be critical.

Generally, after exposure to an ESD, the stability of the resistor is reduced and the degree of instability is directly related to the level of ESD. Temperature coefficient changes have been known to result from such ESD exposure.

For thick film resistors, the resistance shift is negative. The resistance change can easily exceed 50 percent with some thick film pastes. Some exceptions to this may occur, especially at low resistance values.

For thin film, metal film, metal oxide and carbon film at lower ESD levels, small negative resistance shifts of less than 5 percent can be experienced. At higher ESD levels, large positive shifts greater than 10 percent can be experienced, depending on the power rating.

5.4.3.4 Metallization strips. Relatively narrow thin metallization on a substrate such as SiO_2 which carries current between terminals without any other energy absorbing element in the path are susceptible to ESD. These metallizations may consist primarily of aluminum or gold but can also be multi-layered. The failure mechanism is burnout from joule heating. This type of constituent is often used in monolithic integrated circuits, hybrid microcircuits and multiple finger overlay transistor construction found in switching and high frequency transistors. Joule heating is most likely to occur when: (1) the ESD source has very low contact resistance, resulting in high currents over short time constants; and (2) a low resistance large area diode is connected by the metallization path between the two terminals, resulting in large currents due to the low voltage drop in the diode forward biased direction. Increasing the width or thickness of the strip will decrease ESD sensitivity. The use of glassivation and thinner SiO_2 between the strip and the silicon also reduces ESDS. The failure indicator from this failure mode is open.

5.4.5 Passivated field effect structures with nonconductive lids. Various NMOS and PMOS integrated circuit designs have been found to fail from very localized high concentrations of positively charged ions on the outer passivated surface of the die. NMOS designs fail from excessive leakage currents from field inversion between N+ junctions such as thick field parasitic transistors, intermediate field parasitic transistors, EPROM transistors and normal select transistors. PMOS designs such as the floating gate, EPROM or depletion type field effect transistors fail when the negative charge on the floating gate is overcompensated by positive charge clusters on the outer surface of the die. This causes the part to turn off, giving an erroneous unprogrammed indication. The effective field from the positively charged ions needed to create this inversion has been found to exceed 85 volts. Hermetic packages which have recorded this failure mode have nonconductive lids made from nontransparent ceramic, transparent sapphire and transparent borosilicate glass. These failures can be prevented by grounding the bottom surface of the lid over the die or by insulating preventive meausres to avoid electrostatic charging of the nonconductive lid.

5.4.5.1 Part types. This failure mechanism is most common with NMOS and PMOS UV EPROMs having transparent lids. NMOS static RAMS in a ceramic package, however, have also been reported to fail from this ESD failure mechanism. Unless testing shows otherwise, any LSI integrated circuit with nonconductive lids could conceivably have field effect structures which are susceptible to failure from undesirable field inversion or gate threshhold voltage shifting.

5.4.5.2 Failure mechanisms. This failure mechanism involves positively charged ion clusters deposited on the die as a result of air breakdown in the air gap between the die surface and the bottom of the package lid. Charging of the bottom of the lid can be induced by several means, one of which is by freeze spraying the package with canned coolant. The positive charging rate of the freeze spray impinging on the top of the lid depends on the flow rate of the coolant from the can. At low flow rates the charging is negative and does not induce failure; at high flow rates sufficient positive charging can occur to induce failure. The localized air breakdown in the air gap of the package causes ionized streamers to form from the die to the lid. The positive charge on the bottom of the lid drives the positive charge in the streamer toward the die surface and attracts the negative charge toward the lid. This results in very localized clusters of positive ions on the die surface. Because of the nature of the air breakdown for certain package ambients this charge is probably identical in type to the very large ions that can be experimentally created by positive corona discharge in air.

5.4.5.2.1 These localized positive charges also cause the formation of inversion layer leakage paths between N+ diffusions and shift the gate threshhold voltage on PMOS depletion type transistors. The formation of leakage paths and the gate threshhold shifts gives rise to isolated circuit failures.

5.4.5.2.2 This failure mechanism is recoverable by neutralizing the positive charge on the outer surface of the die. On UV EPROM with transparent lids, recovery is nondestructive when 2537Å ultraviolet light with a minimum photon energy of 4.3eV is applied to the chip for as short as 3 to 5 seconds.

5.4.5.3 Failure indicators. The failure indicators for this failure mode come under the general classification of operational degradation. This operational degradation will take the form of a functional failure. In the case of NMOS UV EPROMs, certain programmed bits appear unprogrammed and certain unprogrammed bits appear programmed. In one group of failure indicators, bit failures have been organized in columns where programmed bits appeared unprogrammed. In another group of failure indicators, bit failures were organized in rows where unprogrammed bits appeared programmed.

5.4.5.3.1 The failure indicators for PMOS UV EPROMs are random single bit failures throughout the memory which should read as programmed appeared as unprogrammed.

5.4.5.3.2 The failure indicators for an NMOS static RAM have been reported as random bits stuck in a "1" or "0" logic state and the adjacent cell also stuck but in the opposite logic state.

5.4.6 Piezoelectric crystals. Part types such as quartz crystal oscillators and surface acoustic wave (SAW) devices can fail from ESD, resulting in operational degradation. Electrical parameters of piezoelectric crystals contained within these parts are damaged by excessive driving current. Also, the piezoelectric effect from high voltages causes mechanical stress and movement to be generated in the crystal plate. When the voltage is too excessive, mechanical forces cause motion in excess of the elastic limit of the crystal and crystal fracture occurs. The fracture may occur as a lifted platelet as has been experienced in lithium niobate SAW delay lines. Such fractures when occurring in sufficient number will cause enough change to the operating electrical characteristics to cause failure.

5.4.7 Closely spaced electrodes. When employing thick metallization such as 13,500Å, gaseous arc discharge in an arc gap 50 µm wide can be used as a protection device to dissipate incoming high voltage spikes. For parts with closely spaced unpassivated thin electrodes, however, gaseous arc discharge can cause degraded performance. Parts that employ thin closely spaced electrodes include surface acoustic wave (SAW) devices. Other parts such as high frequency multiple finger transistors and new technology such as very large scale integration (VLSI) and very high speed integration (VHSI) could also be degraded to failure from arc discharge between metallization runs.

The arc discharge causes vaporization and metal movement generally away from the space between the electrodes. The melting and fusing do not move the thin metal into the interelectrode regions but the metal pulls together and flows or opens along the electrode lines. There can be fine metal globules in the gap region but not in sufficient numbers to cause bridging. Shorting is not considered a major problem with unpassivated thin metal electrodes. ESD failures have been experienced on surface acoustic wave (SAW) band pass filters with thin metal of 4,000Å and electrode spacing of 3.0 µm.

6. ESD TESTING

6.1 Human ESD model. People are prime sources of ESD for damaging parts. The test circuit used for ESD testing is therefore based upon a human discharge model. Electrostatic charges generated by rubbing or separating materials are readily transmitted to a person's conductive sweat layer causing that person to be charged. When a charged person handles or comes in close proximity to an ESDS part, he can damage that part from direct discharge by touching the part or by subjecting the part to an electrostatic field. The ESD from a person can be reasonably simulated for test purposes by means of the figure 1 test circuit. This test circuit is also used in MIL-M-38510 and has been widely used in industry to represent a person for ESD testing. The human capacitance, however, may be as high as several thousand picofarads (pF) but more typically 50 to 250 pF. A study performed on human capacitance indicated that approximately 80 percent of the population tested had a capacitance of 100 pF or less. The variation in human capacitance is due to factors such as variations in the amount and type of clothing and shoes worn by personnel and differences in floor materials. Human resistances can range from 100 to 100,000 ohms, but is typically between 1,000 and 5,000 ohms for actions which are considered pertinent to holding or touching parts or containers of parts such as finger-thumb grasp, hand

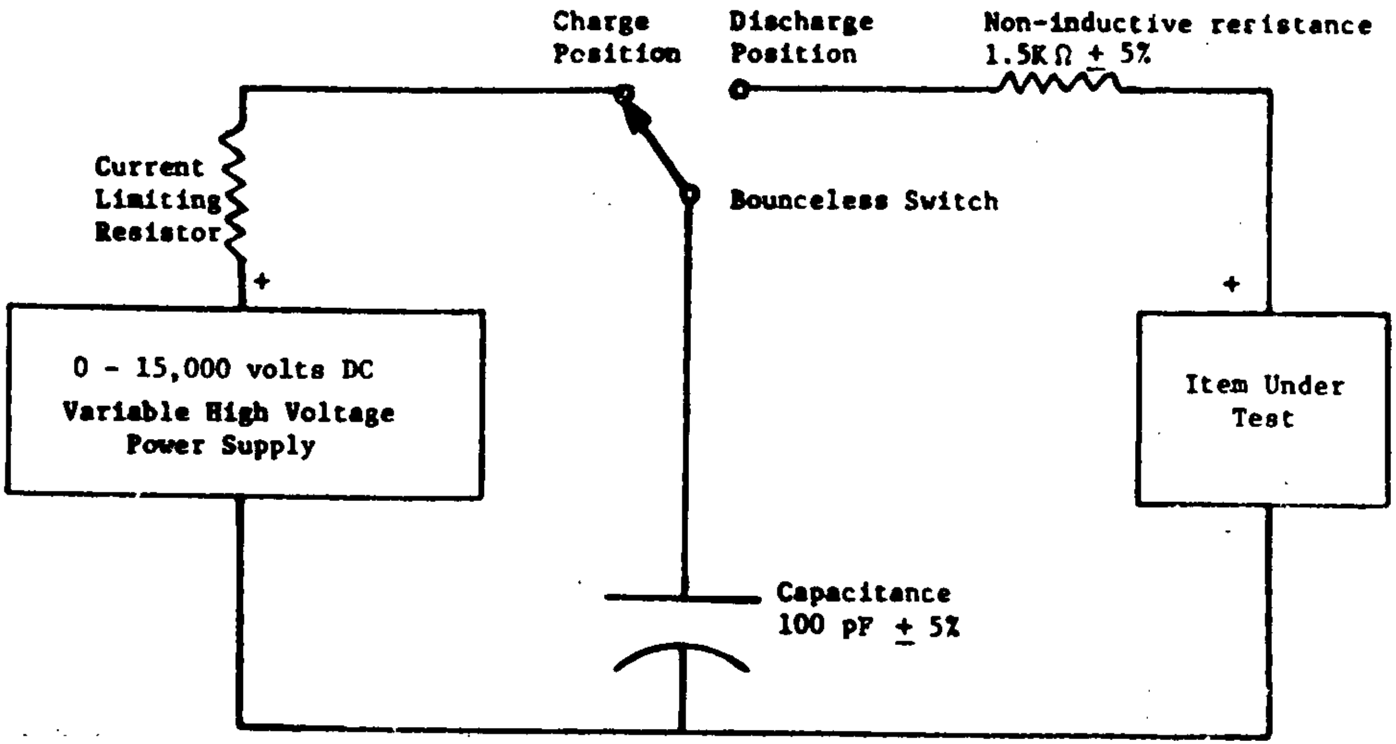

FIGURE 1. ESD test circuit

NOTE: Test voltages are measured across the capacitance. The capacitor shall be discharged through the series resistor into the item under test by maintaining the bounceless switch to the discharge position for a time no shorter than required to decay the capacitor voltage to less than 1 percent of the test voltage or 5 seconds, whichever is less. Power supply voltage shall be within a tolerance of ±5 percent of test voltage.

holding or palm touch. The variation in human resistances is due to factors such as the amount of moisture, salt and oils at the skin surface, skin contact area and pressure. A value of 1,500 ohms provides a reasonable lower human resistance value. In view of the above, the proposed human model using a 100 pF capacitance and a 1,500 ohm resistance is not a worst case human model. For power sensitive parts an increase in human model capacitance to greater than 100 pF could result in damage to ESDS parts at voltage levels below those shown in table IV. For instance, power sensitive parts damaged at 400 volts using the 100 pF, 1,500 ohm human model would be damaged by slightly less than 300 volts had a 250 pF, 1,500 ohm model been used. Therefore, a part not considered as ESDS could actually be ESDS under more stringent human model conditions. For predominately voltage sensitive ESDS parts, a variation in the capacitance value in the test circuit will cause little effect on its sensitivity. A decrease in human model resistance will increase the voltage and power delivered to the part and therefore will likewise cause the voltage level at which damage occurs to decrease. In this case, the predominately voltage sensitive part may have a larger decrease in voltage damage level. The human model of 100 pF, 1,500 ohm is considered to be a reasonable test circuit for standardizing the ESD sensitivity of parts.

6.1.1 Some ESDS parts are voltage sensitive while others are power sensitive. In general, voltage sensitive parts fail due to dielectric breakdown of insulating layers or junctions. Other ESDS parts are power sensitive. That is, the pulse shape, duration and energy can produce power levels resulting in part thermal breakdown when the voltage level is below that needed to cause dielectric breakdown. The power pulse is defined by the test circuit, the part resistance and capacitance (R-C) characteristics, the R-C time constant of the test circuit and the voltage at the capacitor. Thus for a given test circuit with a fixed R-C such as figure 1 and a part with the given R-C, the voltage of the capacitor determines the pulse shape of the power pulse. Therefore, ESD sensitivity can be expressed as a voltage for voltage and power sensitive items for a given test circuit and part.

6.1.1.1 Differentiation between parts that are ESDS and those that are not ESDS is based upon sensitivity to ESD voltage levels of 15,000 volts. This voltage level can be generated in many unprotected areas of typical manufacturing facilities under normal humidity conditions, presence of prime electrostatic generators and typical electrostatic generating movements. Under low humidity conditions or where prime generators of static electricity are present, such as in a packaging area where rolls of plastic sheets are unwound, electrostatic voltages in excess of 40,000 volts can be generated. In such environments many devices normally not considered to be ESDS can be damaged.

6.2 <u>Types of testing</u>. Testing methods are described in the following paragraphs. The test circuit of figure 1 is applicable to all testing. Normally part failure is defined as the inability of a part to meet the electrical parameter limits of the part specification. Any measurable change in a part electrical parameter, due to an ESD could be an indication of part damage, and susceptibility to further degradation and subsequent failure with successive ESDS.

CAUTION NOTE

ESD TESTING SHOULD BE CONSIDERED TO BE DESTRUCTIVE. PARTS SUBJECTED TO ESD TESTING SHOULD NOT BE USED IN DELIVERABLE HARDWARE DUE TO THE POSSIBILITY OF PART DEGRADATION OR LATENT DEFECTS.

6.2.1 Classification testing. Classification testing for determining whether parts are Class 1 or Class 2 is covered by DOD-STD-1686, Appendix B. This testing can be expanded to less sensitive parts by increasing the test voltage levels. The voltage levels used for the critical path determination should be at least 25 percent above the sensitivity voltage limit for the Class for which a part is to be tested. This provides greater assurance for identifying critical paths where they exist due to the variance in sensitivities from one part to another.

6.2.2 Step-stress testing. When it is desired to determine the approximate voltage sensitivity of an ESDS part, a form of step-stress testing could be performed as follows, using a minimum sample size of 10 parts:

a. Conduct tests of part electrical parameters to ensure parts operate within limits specified in the applicable part specification;

b. Apply a voltage at which a part is known to withstand an ESD or at a voltage such as 100 volts. Apply a discharge to the most sensitive critical path pin combination, or one combination at a time when the most sensitive critical path is unknown;

c. Conduct testing of the electrical parameters, in particular those most likely to indicate degradation or damage of each part tested in b. If the same parameter of two or more tested parts does not conform to the applicable part specification, terminate the testing and designate the voltage sensitivity equal to the applied test voltage;

d. If the voltage sensitivity level cannot be determined from the above testing, increase the voltage in steps such as 100 volt increments and conduct electrical parameter tests until at least two parts exhibit a parameter out of specification limits. At voltage levels of 3,000 volts or higher, 1,000 volt increments could be desirable to shorten testing time;

e. If the intent of the testing is to determine the statistical distribution of ESD sensitivity, a sample size of at least 25 parts should be step-stress tested to failure and a histogram plotted showing the number of part failures at different test voltages.

6.2.3 Latent defect testing. The susceptibility of ESDS parts to latent defects can be evaluated by methods such as the following. One method is a form of accelerated testing where ESDS parts are pulsed approximately 25 percent below their known sensitivity levels with multiple discharges until failure occurs. Some ESDS parts are weakened by successive discharges and this weakened condition reduces part life. The use of multiple discharge testing is realistic since parts can be exposed to ESD pulses many times during their life, for example, during production, packaging, transportation, receipt inspection, kitting, assembly, and test. Another method is to subject a sample of parts to single or multiple discharges below their ESD voltage and power sensitivity levels. Parts exhibiting performance characteristics within specification limits are then put on life test with a control sample not subjected to the ESD pulsing. It should be noted that use of elevated temperature to achieve in accelerated life testing may result in healing of dielectric punctures caused by an ESD. Statistical evaluation of the lives of the two samples can be used to determine the effects of ESD latent defect failure mechanisms on part life. Another approach to the evaluation of latent defects can be based upon analysis of failures and historical trends where such data is available.

CAUTION NOTE

DAMAGE DUE TO DISCHARGE TESTING AS PROVIDED ABOVE CAN BE CUMULATIVE FOR SOME PART TYPES. FURTHERMORE, AN EXCESSIVE REPETITION RATE OF DISCHARGES COULD BUILD UP HOT SPOTS IN THE PART AND CAUSE AN ACCELERATION OF THE FAILURE EFFECTS DISCHARGES SHOULD, THEREFORE, BE TIME SPACED TO ALLOW FOR COOLING WITHIN THE PART.

6.2.4 ESD spark testing. Most parts which are sensitive to ESD are also sensitive to magnetic fields and radioactive fields. EMP caused by ESD discharge in the form of a spark can cause part failure and cause equipment such as computers to upset (see 5.2). ESD spark testing can be performed by discharging the ESD in the form of a spark across a spark gap sized for the ESD test voltage or by slowly bringing the high voltage test lead of the test circuit close to the case or electrical terminal of an ESDS item while it is operating until the voltage is discharged in the form of a spark.

6.2.5 Lot sample testing. Another consideration for ESD testing is to perform testing on lot samples of parts used in large quantities. Differences in lots from the same manufacturer and differences between manufacturers often result in variations in ESD sensitivity for the same part type. Lot ESD testing of parts on a sample basis could be used as a quality control check on purchased parts.

6.2.6 Assembly and equipment testing. The use of part testing procedures for an assembly and an equipment may be prohibitive in terms of test sample costs. In such cases, classification techniques for assembly and equipment should be based on: (1) conservatively, the most ESDS part contained in that assembly; or (2) detailed circuit analysis of the voltage protection afforded by the ESD protection circuitry incorporated for the ESDS parts in that assembly or equipment.

6.2.6.1 The second technique partially limits the requirements of rigorous ESD protective controls to only those assemblies and equipment which are ESDS. This second approach can result in an optimistic categorization of ESDS assemblies since the ESD protection circuitry may not provide protection against ESD induced by electrostatic fields or by direct ESD through single point contact with the part body or connections of the PWB. This can occur regardless of whether or not the printed circuitry assembly is conformally coated.

6.2.6.2 The high cost of repair after ESD testing at the assembly or equipment level may be justified where large production quantities are involved. Such testing would be valuable in verifying the ability of the equipment or assembly protective circuitry to protect highly sensitive ESDS parts.

7. PROTECTED AREAS. The key to a successful ESD control program is the protected area which includes the ESD grounded work bench. Whenever an ESD item is handled outside of its ESD protective packaging, means should be provided to keep electrostatic voltages below the sensitivity level of ESDS items. The lower the level of the static generated voltage below the ESDS item sensitivity level, the greater is the probability of protecting that item.

The sophistication to which a protected area can be designed depends upon the level of assembly and maintenance (e.g., equipment or assembly, organizational, intermediate or depot); and for physical limitations of the work area or facility. For example, for field maintenance, a protected area could consist of an area kept free from static generators and equipped with: a personnel wrist ground strap; a portable protective work mat; and use of ESD protective packaging for repair parts and spares. A protected area in a manufacturing facility, on the other hand, could include humidity controls, an elaborate grounded work bench made of ESD protective materials, personnel wrist ground straps, and equipped with grounded tools and test equipment, conductive flooring, air ionizers and other protective equipment.

Tradeoffs should be performed to determine a balance between the cost of constructing protected areas versus the complexity of the handling procedures to be implemented to attain the required controls. For example, training and controls should consider the ability and willingness of people to follow elaborate handling procedures and use certain ESD protective materials and equipment such as wrist and ankle straps.

For purposes of simplicity a contractor may desire to consider all ESDS items as highly sensitive to standardize controls throughout the facility or implement only those controls needed for the sensitivity of the items pertaining to a specific protected area.

One of the basic principles in the design of the protected area is to prohibit the use of prime generators (see table II) in the design and construction and restrict the entry of these prime generators by personnel working in these areas. Protected areas and work benches should be identified by signs; for instance, "ESD PROTECTED AREA": "USE PRECAUTIONS WHEN HANDLING ESDS ITEMS OUTSIDE OF THEIR PROTECTIVE WRAPS". Access to protected areas should be restricted to people who are properly trained and attired, or who are escorted, cautioned in protective procedures, and are restricted from contacting ESDS items. Areas should be constructed using the materials and equipment such as listed in 7.1 and 7.2.

7.1 ESD protective materials. The primary protective properties of ESD protective materials include:

a. Protection against triboelectric generation;

b. Protection from electrostatic fields;

c. Protection against direct discharge from contact with charged people or a charged object.

It is difficult to find one material that provides all of the above properties. Often, it is necessary to use a combination of different protective materials to achieve the desired results.

Protection against the generation of electrostatic charges is the best method of ESD control. If materials do not generate electrostatic charges no further action is required. One of the prime characteristics of materials in reducing the generation of static is lubricity, which is a measure of surface smoothness and lubricating action of moistness. Triboelectric generation is a friction process, the higher the lubricity of the surfaces being rubbed, the lower the friction and hence the lower the generated charges. Moistness on the surface of materials being separated provides progressive neutralization of opposite charges by furnishing a conductive path between the surfaces until separation is complete. Once a charge is generated the distribution of that charge is dependent upon the resistivity and surface area of the material. The more conductive the material the faster the charge is distributed. The greater the surface area over which a charge is spread, the lower the charge density and the level of the residual voltage. In contrast to insulators, localized charges cannot exist on conductors.

Conductivity is also a prime characteristic for providing protection against stationary or approaching charged bodies or people by limiting accumulation of residual voltages. A polarization occurs gradually as the charged body or person approaches limiting the voltage levels induced across the conductive surface. In conductive materials these electrons move quite rapidly resulting in low voltages applied across the ESD protective material. As the resistivity of the material increases such as in the case of static dissipative and anti-static materials, the electrons move more slowly and higher voltages result across the material. If the voltage of the charged body is high enough, and approaches a tote box or table top which is highly conductive, a spark could occur. The more conductive the material, the higher the probability of creating a spark and the higher the discharge current. Higher discharge currents conducted through a part increases its probability of failure. The tote box or table top should be conductive enough so that significant voltages will not be induced across the tote box or table top, but not be so conductive so that a spark discharge will occur.

Complete shielding from electrostatic fields or ESD high voltage spark induced EMP requires enclosing the item in a conductive material. Normally, the greater the conductivity of the enclosure the greater the attenuation of the electrostatic field and ESD high voltage spark induced EMP within the enclosure.

The protective characteristics of materials needed to protect ESDS items from direct discharge from a charged body or person depends upon the method of discharge. If the discharge is through an ESDS item a high resistance to ground is beneficial in reducing the voltage across ESDS items since the greater part of voltage drop is across the resistance to ground and the discharge current through the ESDS item is limited.

7.1.1 Material resistivity. Measurement parameters commonly used in describing the resistive properties of materials used for protection agains ESD are commonly referred to as:

a. Volume resistivity (ohms-cm)
b. Surface resistivity (ohms per square)
c. Decay time (seconds)

7.1.1.1 Volume resistivity (ρV). Volume resistivity, also referred to as bulk resistivity, is a constant for a given homogeneous material and is mathematically derived as follows:

From electrical theory, the resistance (R) of a piece of material is inversely proportional to the cross-sectional area (A) perpendicular to the flow of current and directly proportional to the length of material (ℓ) parallel to the flow of the current.

$$R \propto \frac{\ell}{A} \quad \text{.......... (1)}$$

therefore,

$$R = (\text{constant}) \frac{\ell}{A} \quad \text{.......... (2)}$$

This constant, known as volume resistivity (ρV), is published for various homogeneous materials, and has dimensions of ohm-cm^2/cm or ohm-cm.

$$\rho_V = \frac{RA}{\ell} \quad \text{.......... (3)}$$

The resistivity of a homogeneous material is determined by measuring the resistance of a piece of the material with known dimensions (i.e., length (ℓ), width (w) and thickness (t).

For a square piece of material "ℓ" is equal to "w" and equation (3) reduces to:

$$\rho_V = Rt \quad \text{.......... (4)}$$

It is evident from equation (2) that the resistance (R) of a bulk conductive material, such as a bench top, tote box or parts tray, with a given ρ_V can be varied by varying the thickness of the material. ρ_V is normally determined by measuring the resistance (R) of a square of material and multiplying R by the thickness (t) (equation (4)).

7.1.1.2 Surface resistivity (ρs). Surface resistivity (ρ_s) is a measu of the resistance (R) of a square section of material and is normally used as a resistivity measurement of a thin conductive layer of material over a relatively insulative base material, but is applicable also to volume conductive materials. ρ_s has the dimensions of ohms per square and is measured across the surface of the material. ρ_s is equivalent to the resistance measurement (R) taken for determining volume resistivity for a square section of material.

$$\rho_s = R \text{ (when the area of the specimen is square)} \quad \ldots\ldots\ldots (5)$$

Of the two resistivity parameters, the surface resistivity is the more representative resistivity measurement because it is a measure of the effective material resistance for a given piece of material. However, it should be noted that resistivity measurements are performed on square pieces of material using the electrodes along opposite sides of the material square. Most objects made of ESD protective materials are not square and normally the electrical points of contact do not encompass the complete opposite edges of the object. Consequently, surface resistivity is only an approximation of the actual resistance of the path between the two electrical contact points, such as a person's hand or finger and a ground connection. The actual resistance can be calculated using equation (3), or measured with an ohm or megohmmeter, using representative electrical contact sizes and shapes to stimulate a person's hand and the ground point.

$$\rho_s = \frac{\rho_v}{t} \quad \ldots\ldots\ldots (6)$$

or,

$$\rho_s t = \rho_v \quad \ldots\ldots\ldots (7)$$

Equations (6) and (7) show that ρ_s is not constant for a homogeneous material but varies with material thickness (t). Therefore, the relationship of ρ_s to ρ_v is meaningless for a homogeneous bulk conductive material unless the thickness (t) is also given.

Since surface resistivity is commonly used as a resistance measurement parameter of laminated materials having a thin conductive surface over an insulative base, it is used to measure the resistivity of surface conductive materials such as: hygroscopic anti-static polyethylenes, nylon and virgin cotton, metal or carbon coated paper, plastics, and other conductively coated or laminated insulative materials. Conductive layers on these materials are usually of near uniform thickness such as the sweat layer of hygroscopically anti-static material, and the surface resistivity does not effectively change by increasing or decreasing the thickness of the base insulative material if its ρ_v is high in relation to that of the conductive surface material.

7.1.1.3 Decay time. Decay time is an indirect method of measuring material surface resistivity. Decay time is measured by charging a section of material with a static voltage and measuring the time for the voltage to decay to a given level such as 10 percent of its original value. Hygroscopic anti-static materials will show variations in decay time at different relative humidities. Decay time measurements are used to specify the electrostatic properties for MIL-B-81705 material and is generally directly proportional to surface resistivity.

7.1.2 Classification of ESD protective materials. There are three basic classifications of ESD protective materials which are based upon ranges of surface resistivity. It should be noted that these ranges are relative and no sharp demarcations exist at extremes of these ranges. Treatment of materials with coatings that decrease surface resistivity will result in reclassification of a material to a more conductive category.

7.1.2.1 Conductive protective materials. Conductive ESD protective materials are defined herein as materials having surface resistivities of 10^5 ohms per square or less. Materials such as metals, bulk conductive plastics (e.g., MIL-P-82646), wire impregnated materials and conductive laminates, can be capable of meeting this resistivity requirement except for very thin pieces of bulk conductive materials or material with sparsely woven wires or wire mesh. From equation (6) it is evident that a bulk conductive material with a volume resistivity of 10^4 ohm-cm would be conductive based upon a minimum thickness of 0.1 cm ($\rho s = \rho_V/t$). Material thickness of less than 0.1 cm would classify this material as static dissipative rather than conductive.

7.1.2.2 Static dissipative protective materials. Static dissipative materials are those materials having surface resistivities of $>10^5$ and $<10^9$ ohms per square. Static dissipative material could include the same materials as conductive materials except that the thicknesses are lower, wire or wire mesh included therein is finer or more space than in conductive materials or volume resistivities are higher.

7.1.2.3 Anti-static protective materials. Anti-static materials are those materials having surface resistivites of $\geq 10^9$ and $\leq 10^{14}$ ohms per square. These materials include hygroscopic anti-static materials such as MIL-B-81705 Type II, some melamine laminates, high resistance bulk conductive plastics, virgin cotton, cellulose based hardboards, wood and paper products, and static dissipative or conductive materials having very small thicknesses.

7.1.3 Resistivity measurement. Two existing test procedures for measuring the resistivities of conductive, static dissipative and anti-static materials are:

a. American Society of Testing Materials procedure, ASTM-D-991 for conductive materials;

b. American Society of Testing Materials procedure, ASTM-D-257 for static dissipative, anti-static and insulating materials.

Additionally the method for measuring decay time is provided in Federal Test Method Standard No. 101, Test Method No. 4046, "Electrostatic Properties of Material".

7.1.4 Triboelectric properties. Many anti-static materials such as: MIL-B-81705 Type II, virgin cotton, unfinished wood and some paper products provide good protection against generation of static electricity from triboelectric effect. As described in 4.2, the amount of charge created by triboelectric effect is dependent upon factors such as surface smoothness, lubricity, contact area, pressure, and speed of rubbing.

Hygroscopic type anti-static materials possessing sweat layers have good lubricity characteristics and generally are poor generators of static.

Many conductive and static dissipative materials also provide protection from triboelectric generation. Some metals, however, will create significant charges from triboelectric generation as is indicated in the triboelectric series. Aluminum, for example, when rubbed with a common plastic can generate substantial electrostatic charges. Although a conductive material distributes a charge over its surface, the other substance with which it is rubbed or from which it is separated, especially if it is insulative, can become highly charged.

7.1.4.1 Triboelectric measurement. Triboelectric generation is relative between two different materials. There are numerous variables that affect the amount of charge or voltage generated by triboelectric action which have not been standardized. No standardized methods, therefore, have been developed for triboelectric generation measurements. Fixtures have been developed to measure triboelectric generation of materials but are limited in their capabilities and require stringent controls. A more limited but practical method of estimating the triboelectric generation capability of a material is to rub that material briskly or separate it from a known static generator such as common polyethylene and measure the resultant voltages on either or both materials with an electrostatic field meter. This test can be used on bench tops, packaging materials, floors, clothing or any other material. Conductive or static dissipative materials will generally distribute the charges over these surfaces faster than the meter can respond, disallowing accurate measurements. If conductive or static dissipative materials are held or touched by a person during the rubbing or separation action, the charge will be conducted to the person, again invalidating the test results.

7.1.5 Shaped forms. ESD protective materials whether conductive, static dissipative or anti-static, are capable of being formed into many shapes. For example, metals can be cast, stamped or pieces welded into most any shape while most conductive, static dissipative and anti-static plastic materials can be molded into formed shapes. Fiberboard, melamine laminates and other materials in laminated or homogenous form can be constructed into boxes and various other shapes. Available formed shapes include the following:

a. Sheets and plates - provided in various sizes and thicknesses for use as work bench tops, floors, floor mats, wraps and coverings;

b. Formed parts trays, vials, carriers, boxes, bottles and other custom shapes;

c. Rigid shorting bars and clips - used for electrical shorting of ESDS part leads and higher assembly connectors;

d. Foam used for shorting part leads, assembly connectors, or as a cushioning for packaging;

e. Bubble pack material or open cell plastic foam - used for a cushioning for packaging such as MIL-P-81997 and PPP-C-1842 Type III Style A);

f. Flexible materials in the form of bags such as MIL-B-82467, trash can liners, seat covers, and personnel apparel including smocks, gauntlets and finger cots;

g. Personnel ground straps - insulated wire or flexible straps of the conductive plastic used in the form of personnel ground strap cables;

h. Heel grounders - flexible formed strips of the conductive plastics placed inside the shoe and connected to the outside shoe heel used to ground personnel to the bottom of the shoe heel;

i. Conductive shoes - conductive rubber or plastic inner and outer soles and heels;

j. Conductive, static dissipative and anti-static carpeting and flooring, including carbon impregnated vinyl tiles and terrazzo floors.

7.1.6 Application information of ESD protective materials. General application for the three classifications of ESD protective materials are provided in table VI. Additional application information for various formed shapes of ESD protective materials is provided in table VII. It should be noted that the information provided in these tables is relative from one material type to another. Also, it should be emphasized again that there are no clear demarcations between the three types of materials listed, that is, the properties of a conductive material at the higher end of its resistivity range could be equivalent in properties to a static dissipative material at the lower end of its resistivity range.

7.1.7 Topical antistats. Topical antistats are chemical agents which when applied to surfaces of insulative materials will reduce their ability to generate static. Topical antistats are generally liquids consisting of a carrier and an antistat. The carrier is the vehicle used to transport the antistat to a material. It acts as a solvent and can be water, alcohol or mineral spirits, or other compatible material. The antistat is the material which remains deposited on the material surface after the carrier evaporates and provides the static control function. Some antistats are detergent type materials which when combined with the moisture in the air wet the surface of the material on which they are deposited. These antistats are classified as hygroscopic and their effectiveness is reduced under low relative humidity. Other antistats are available which are not as humidity dependent. They reduce the generation of static by increasing surface lubricity and surface conductivity. Generally, varying the ratio of antistat and carrier will provide surface resistance control when appropriately applied to the material. The primary effect of topical antistats is to reduce the static generation by triboelectric effect. Topical antistats can be brushed, sprayed, rolled, dipped, mopped, wiped or otherwise applied to floors, carpets, work bench tops, parts trays, parts carriers, chairs, walls, ceilings, tools, paper, plastics and clothing to render them ESD protective to varying degrees. Some antistats are also good cleaners and can be mixed with water to clean surfaces such as floors and bench tops and at the same time render them anti-static.

TABLE VI. General application information for different types of ESD protective formed shapes

Application	Conductive	Static Dissipative	Anti-Static
General application considerations	1. Could present a personnel safety hazard when contacting high voltages and hard grounds. 2. Could damage electrical circuitry of parts or assemblies during testing if electrical connections contact conductive surfaces. 3. Steels (except corrosion resistant) are prone to corrosion. Protective coatings such as paint will destroy the surface conductive properties and could be static generative. 4. Aluminum will form aluminum oxide on its surface reducing conductivity and increasing its ability to generate static. 5. Hard surfaces such as metal provide little protection from physical shock to items dropped thereon	1. Presents the same hazards as listed under "Conductive" 1 and 2 except to a lesser degree. Hazards depend upon the magnitude of the voltages and the types of parts and circuits tested. 2. See item (6) under "Conductive". 3. See item (7) under "Conductive".	1. The effectiveness of hygroscopic antistatic materials are reduced in low relative humidities since their antistatic properties are dependent upon absorbing moisture from the air. 2. The accumulation of dirt, oils and silicone have an adverse effect on the anti-static properties of hygroscopic antistats. Cleaning with solvents such as alcohols, ketones and other hydrocarbon based solvents can remove the antistats. May require periodic treatment with a topical antistat. 3. Antistats used in some hygroscopic anti-static materials can track onto items and act as a foreign substance which could react with other materials

TABLE VI. General application information for different types of ESD protective formed shapes (Cont'd)

Application	Conductive	Static Dissipative	Anti-Static
	6. Materials should be reviewed for flammability, corrosivity, toxicity, bacterial growth, crumbling, powdering, shedding, flaking, brittleness, outgassing, long term chemical reaction with parts. 7. Protection against triboelectric generation depends upon the material used. (See 7.1.4).		3. (Cont'd). adversely. This has been shown to be a problem with the lubricant in miniature bearings. 4. See item (6) under "Conductive". 5. Hygroscopic antistatic materials generally provide protection against triboelectric generation. The triboelectric generation characteristics of other anti-static materials depends upon the material used (See 7.1.4).

TABLE VII. Additional application information for different types of ESD protective formed shapes

Application	Conductive	Static Dissipative	Anti-Static
Bench tops (Also see 7.2.8)	1. Dissipates charges rapidly throughout the material and to ground, and will not maintain a high static voltage. 2. Could discharge an ESD in the form of a spark causing EMP. 3. Could cause a high current discharge through an ESDS part. 4. Could present a safety hazard or short if a high voltage source contacted the bench top. Could hard ground the table top if test equipment with grounded chassis contacted the bench top surface. 5. Safety could require that series resistances be provided in connection to ground where high voltages can be contacted by personnel.	1. Charge dissipation rate generally adequate for most ESDS parts. 2. Provides greater resistance for personnel protection from high voltages or hard grounding if the table top is contacted with test equipment ground. 3. Reduces discharge currents through ESDS parts. 4. Safety could require that series resistances be provided in connection to ground where high voltages can be contacted by personnel.	1. Provides slow bleed-off of static charges. If ground straps are used by personnel working at the work bench high ESD voltages should be rapidly dissipated through the ground strap. 2. Reduces the possibility of a spark from ESD. 3. Limits discharge currents through ESDS parts to low levels. 4. Generally provides adequate resistance for personnel safety.

TABLE VII. Additional application information for different types of ESD protective formed shapes (Cont'd)

Application	Conductive	Static Dissipative	Anti-Static
Floor mats (should be used with conductive shoes or heel grounders) (Also see 7.2.3)	1. Dissipates charges rapidly throughout the material and to ground, and will not maintain a high static voltage. 2. Safety could require that series resistances be provided in connection to ground where high voltages can be contacted by personnel.	1. Provides adequate conductivity for dissipation of charges. 2. Generally provides sufficient resistance for personnel safety. External series resistance to ground may not be required.	1. Provides slow bleed-off of high static charges. 2. Accumulations of dirt, contaminants and wear reduce anti-static properties. Requires frequent cleaning and treatment with a topical antistat.
Packaging Material (bags and other containers used to enclose ESDS items. Note: Combination of different ESD protective materials may be required to provide the best protection from triboelectric generation, direct discharge and electrostatic fields. Multi-layered packaging containers using different types of ESD protective materials as intimate and outside wraps are available.	1. Provides protection of highly sensitive ESDS items from high ESD voltages. 2. Provides protection of ESDS items from electrostatic fields. 3. Thin metallized coatings on some containers can be abraded reducing shielding effectiveness from electrostatic fields.	1. Provides protection of moderately sensitive ESDS items from high ESD voltages. 2. Provides protection of highly sensitive ESDS items from moderate voltages. 3. Provides moderate protection of ESDS items from electrostatic fields.	1. Provides protection of moderately sensitive ESDS items from moderate ESD voltages, highly sensitive items from low voltages.

TABLE VII. Additional application information for different types of ESD protective formed shapes (Cont'd)

Application	Conductive	Static Dissipative	Anti-Static
Tote boxes and parts trays	1. Same as for packaging material except that openings in box or tray could reduce protection from electrostatic fields.	1. Same as for packaging material except that openings in box or tray could reduce protection from electrostatic fields.	1. Same as for packaging material except that openings in box or tray could reduce protection from electrostatic fields.
Shunt bars, clips, foam (Also see 7.2.9)	1. Provides low impedance shunt and good protection for ESDS parts.	1. Provides relatively high impedance shunt which could be suitable for ESDS parts with impedances considerably higher than the shunt impedance.	1. Typically is too high in resistance to act as a good shunt.
Personnel Apparel (smocks, gauntlets, finger cots, etc.) (Also see 7.2.7)	1. Provides good dissipation over its surface and will conduct charges from a person's body to ground if a ground strap is worn.	1. Provides good dissipation over its surface and will conduct charges from a person's body to ground if a ground strap is worn.	1. Provides slow bleed-off of charges from person's body to ground when a strap is worn.

Caution should be observed that the topical antistats are not applied to electrical circuit boards, parts or assemblies since they can increase conductivity or possibly affect solderability. Topical antistats can be removed during cleaning operations and the cleaned surfaces may require re-treatment. Topical antistats can provide protection for an extended period of time depending upon factors such as application rate and the amount of handling. Their effectiveness should be periodically checked: by rubbing with a material such as common polyethylene and monitoring the charge and its decay time with an electrostatic field meter, or by measuring the surface resistivity of a sample of the material using appropriate test equipment (see 7.1.3). Items made of ESD protective materials that require periodic treatment with a topical antistat should have a sticker showing the date that the ESD protective properties of these items should be rechecked. Such items could include tote boxes, trays and gauntlets.

Characteristics to be considered in selecting an antistat in addition to its anti-static properties include:

a. Inhibits bacterial growth;

b. Non-toxicity;

c. Non-corrosivity;

d. Non-flammability;

e. Non-irritating to personnel.

7.2 <u>ESD protective equipment</u>.

7.2.1 <u>Ionizers</u>. Ionizers dissipate electrostatic charges by ionizing air molecules, forming both positive and negative ions. The positive ions are attracted to negatively charged bodies and negative ions to positively charged bodies, resulting in charge neutralization.

7.2.1.1 Ionized air can be used where effective grounding cannot be accomplished to bleed-off static charges, or to dissipate charges on insulators where grounding would not be effective. Ionizers are also useful in dissipating charges where spraying actions such as sandblasting and painting are performed. Three methods commonly employed to ionize air are radioactive, electric and static comb. Radioactive material provides alpha particles which ionize the air. The electrical method employs a high voltage square wave signal to ionize air. The static comb, similar to the lightning rod concept, employs needle points where the charge concentration on the point can ionize air. This is based on the principle that self-repulsion of charge from a non-spherical body will cause the charge to concentrate on the surface having the least radius of curvature. The radioactive material used in ionized air blowers is provided under license from the U.S. Nuclear Regulatory Commission and therefore blowers using radioactive materials are leased. In addition, due to half-life considerations, the radioactive materials must be replaced periodically, typically once a year.

7.2.1.2 Air from ionizers should contain nearly equal amounts of positive and negative ions to dissipate both the negative and positive charges produced when static electricity is generated. An imbalance of positive and negative ions can result in residual voltages over the ionized area. Placement of ionizers should be in accordance with the manufacturer's recommendations or as determined through experience. Manufacturer's specifications normally provide data with respect to decay time versus the distance and the angle of the ionizer to the charged area. Ionizers can take several seconds or even minutes to dissipate charges, depending upon the amount of charge and the distance of the charge from the ionizing source. Ionizers should be turned on for at least 2 to 3 minutes to allow charges in the area to be neutralized. Some ionizers can leave residual voltages high enough to damage some sensitive ESDS items. Selection and placement of ionizers for adequate ESD control will require measurement of residual voltages in the area to be protected and comparison with the voltage sensitivity levels of ESDS items being handled.

7.2.1.3 From an occupational health standpoint it should be noted that: some ionizers develop high voltages which could cause dangerous electrical shock to personnel; other considerations in the use of electrical ionizers are the development of electromagnetic interference and the production of ozone which can cause nausea in personnel. (NOTE: Code of Federal Regulations Occupational Safety and Health Standard, Air Contaminants, Part 1910.1000, Chapter XVII, Title 29, defines the maximum allowable concentration for ozone in a personnel work area). Nuclear ionizers could affect radiation detecting film badges worn by persons in nuclear areas.

7.2.2 Electrostatic detectors. Types of electrostatic detectors include electrometer amplifiers, electrostatic voltmeters, electrostatic field meters, and leaf deflection electroscopes. Commonly used detectors include electrostatic field meters which are battery operated and portable. Field meters provide readings of the electrostatic fields produced by charged bodies using a non-contact probe or sensor, and provide readings in electrostatic field strength or electrostatic voltage at a calibrated distance from a charged body. Some electrostatic field meters use radioactive sources similar to those of radioactive ionizers. Nuclear meters will cause beta fogging of radiation detecting film badges under certain circumstances, resulting in possible false radiation exposure indications. Their use aboard nuclear powered vehicles or in other areas containing nuclear equipment is not advisable. Electrostatic detectors can be used for monitoring the magnitude of electrostatic charges existing on materials, objects or people. Additionally, they can be used to measure the approximate magnitude of electrostatic charges generated by personnel movements and the triboelectric charges generated by rubbing two substances together. Electrostatic meters can also be used to evaluate the ability of packaging material to shield against electrostatic fields by enclosing the meter probe or sensor inside the packaging material and moving a charged object near and around the covered probe.

7.2.2.1 A basic limitation of electrostatic meters is their response time. Most meters are incapable of responding to pulses with fast rise and short pulse widths. For measurement of pulses with very fast rise and decay times, a high speed storage oscilloscope can be used for static charges that are generated and dissipated in shorter times than the response time of a meter.

7.2.2.2 For casual monitoring and for certifying ESD protected areas where Class 2 or Class 3 items are handled, small portable electrostatic field meters may be used. However, for certifying areas where Class 1 items are handled, more accurate laboratory-type detectors may be required. In summary, characteristics to consider in selecting an electrostatic detector are:

a. Sensitivity in terms of minimum voltage level that can be accurately measured;

b. Response time;

c. Range of voltage that can be measured;

d. Accuracy in various ranges;

e. Radioactive or electrically operated;

f. Portability;

g. Ruggedness;

h. Simplicity of operation and readability;

i. Accessories such as remote probes and strip chart recorder output.

7.2.3 Protective flooring. Protective flooring materials are available in the form of conductive, static dissipative and anti-static carpeting, vinyl sheeting, vinyl floor tiles and terrazzo. Conductive adhesives should be used in applying conductive vinyl flooring. Hard surfaced flooring should not be waxed since waxed surfaces are highly resistive and prone to static generation. Conductive shoes, shoe covers or heel grounders should be used to discharge people when employing conductive floors. These items should only be worn in the ESD protected areas and should be kept clean so that contaminants do not inhibit their conductive interface with the floor. People sitting at work benches in an ESD protected area often lift their feet from the floor to the work stool, thus eliminating the benefits of the flooring. Therefore, the use of grounded conductive work stools are often needed with protective flooring. When conductive floors are wired to ground they should contain a suitable resistance to limit current to a safe level.

7.2.3.1 Painted or sealed concrete floors and finished wood floors are typically prime generators of static electricity and should be covered with ESD protective flooring or floor mats, or treated with a topical antistat. The flooring should be periodically tested by measuring the amount of charge generated by personnel walking across the floor, using an electrostatic field meter.

7.2.4 Static sensors and alarms. Static level alarm systems are available for constantly monitoring the levels of static electricity generated in a protected area. Some systems have multiple remote sensors which can monitor several stations simultaneously. Some systems also contain strip chart recorders which provide a permanent record of static levels within an area.

7.2.5 Transient suppressors. Some transient suppressors, depending on the pulse width and shape, could reduce the voltage and energy flowing into an electrical circuit to levels sufficiently low to avoid damage to parts at the assembly levels. Suppressors include tin, zinc or bismuth oxide voltage-dependent resistors (VDRs), often referred to as metal oxide varistors, Silicon Voltage Limiters, R-C Networks and Selenium Stacks. Prior to making an ultimate judgment on any given type of suppressor, a final analysis should consider voltage levels to be encountered, response time of the suppressor, peak current, leakage current, energy absorption, operating temperature range, life, size and cost, and the voltage protection level desired.

7.2.6 Personnel ground straps. Personnel handling ESDS items should wear a skin-contact wrist, leg or ankle ground strap. The function of such straps is to rapidly dissipate personnel static charges safely to ground and equalize personnel static levels with that of the work surfaces. In lieu of a personnel ground strap, alternate personnel grounding methods could be used consisting of conductive shoes, conductive chairs, heel grounders, and ESD protective floors (see 7.2.3).

7.2.6.1 Personnel ground strap considerations. Wrist, ankle, and leg ground straps should have a minimum resistance needed to prevent these grounds from posing a personnel safety hazard. For example, a typical 250,000 ohms resistance ground strap will protect people up to 1,250 volts AC RMS or DC by limiting current to 5 milliamperes (see figure 2). The resistance to ground should be kept to a minimum since higher resistances to ground increase residual voltages on people performing static generating motions (see 7.3.3.2.1). Personnel ground straps are basically of two types:

a. Carbon impregnated plastic ground straps incorporate their own built-in resistance. This type of strap should be insulated over its length to prevent it from touching a hard ground and, thereby providing a low resistance to ground;

b. Insulated metal conductor ground straps containing a series resistor are commonly used. The resistor should be located near the point of contact to the person's skin to reduce the chances of the cable shorting to ground such as by fraying and shunting the strap's resistance.

The personnel ground strap should be connected to the work bench top at a common terminal where the work bench cable to ground is also connected (see figure 2). This grounding technique equalizes the potentials between the person and the work bench top.

The personnel ground strap should contain an alligator clip or other quick release mechanism at its connection to the work bench so that the strap will release in emergencies without injury to the person. The strap should also have an easy release connection at the point of contact to the wrist, andkle or leg as an added safety precaution and for ease of disconnect when the person leaves the work area.

7.2.7 Personnel apparel. People handling ESDS items should wear long sleeved protective smocks or close-fitting, short sleeved shirts or blouses. Long sleeves of shirts or blouses should be rolled up or covered with protective gauntlets banded to the bare wrist and extending toward the elbow. Gauntlets covering the wrists to elbows can be used to cover long sleeved apparel which is not made of ESD protective material. Some working situations could require additional protection, such as the use of aprons made of ESD protective materials. Finger cots where used should also be of ESD protective materials. Smocks, gloves or finger cots of common plastic, rubber or nylon should never be used in protected areas. Protective apparel should be frequently checked, especially after cleaning, by scanning personnel with an electrostatic field meter to monitor for damaging ESD voltages.

7.2.8 Grounded work benches. Work benches which contact ESDS items and personnel should have ESD protective work surfaces (see 7.1) over the area where ESDS items would be placed. Personnel ground straps are a necessary supplement to ESD protective work bench surfaces to prevent people from discharging an ESD through an ESDS item to the work bench surface. Work bench surfaces should be connected to ground through a ground cable. The resistance in the bench top ground cable should be located at or near the point of contact with the work bench top and should be high enough to limit any leakage current to 5 milliamperes or less considering the highest voltage source within reach of grounded people and all parallel resistances to ground such as wrist ground straps, table tops and conductive floors. See figure 2 for a typical ESD grounded work bench.

7.2.9 Shunting bars, clips, conductive foams. The terminals of ESDS items should be shorted together using metal shunting bars, metal clips or non-corrosive conductive foams (see 7.1). To act as an adequate shunt, the resistance of the shunting material should be orders of magnitude below the minimum impedance between any two pins of the ESDS part. Shunts will not always protect an item from an ESD. ESDS parts with non-conductive cases, or assemblies subjected to electrostatic fields or direct ESD could result in damaging induced current flow within the ESDS item to the shunt. For parts with metal cases the shunt should also contact the case. For parts with non-conductive cases and for ESDS assemblies, the shunting materials should be wrapped around the ESDS item.

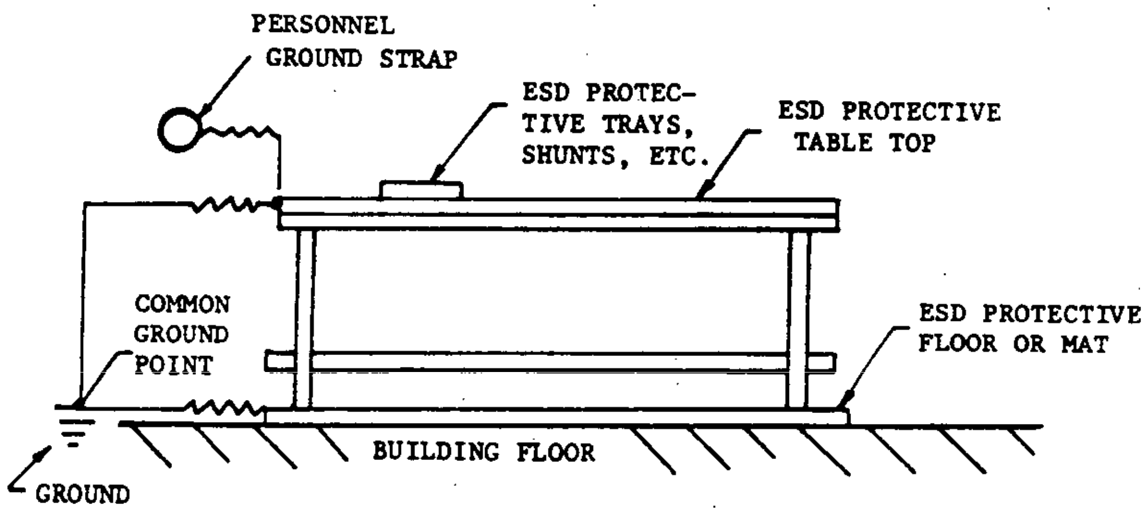

FIGURE 2. Typical ESD grounded work bench

7.2.10 Electrical equipment, tools, soldering irons, solder pots, flow soldering equipment. Soldering irons, solder pots, or flow soldering equipment should be hard grounded and transformer or direct current isolated from the power line. The resistance reading from the tip of a hot soldering iron to ground should be less than 20 ohms so that the voltage buildup will be less than 15 volts. Other electrical power equipment which comes into contact with ESDS items should also be grounded. ESD protective solder suckers such as the metallized or protective types should be used. Insulated handles of hand tools should be checked for static generation and periodically treated with an antistat if required. Small hand tools which have been frequently handled often accumulate skin moisture which may render them ESD protective.

7.2.11 Test equipment. Test equipment should have all exposed metallic surfaces electrically connected via a grounded plug to the test equipment power system or other hard ground. For personnel safety from electrical shock, test equipment should not be placed on conductive work bench surfaces since it could result in hard grounding that surface. Test equipment could be placed on high resistance anti-static material depending upon the magnitude of nearby voltage sources. Ground fault interruptors should be used in electrical receptacles used for powering test equipment as an added personnel safety precaution.

7.2.12 Temperature chambers. Temperature chambers should be equipped with grounded baffles to dissipate charges in circulated air. Alternately, ionized air can be used in the chamber to dissipate static charges caused by air flow, or shields can be used to divert the charged air away from ESDS items in the chamber. Caution should be used in cooling chambers with CO_2 since the evaporation of the CO_2 can generate high static charges. Parts tested in temperature chambers should be placed in ESD protective tote boxes or trays on grounded metal racks within the chamber. The thermal stability of ESD protective materials used in temperature chambers should be suitable over the test temperature ranges.

7.2.13 Spraying, cleaning, painting, and sandblasting equipment. Ionized air blowers, conductive solvents, or ionized nozzles should be used as applicable to prevent electrostatic charge buildup in the work area when spraying, cleaning, painting or sandblasting ESDS items. The use of a wet blast conductive or antistatically treated slurry with a maximum volume resistivity of 500 ohms-cm should be used instead of dry sandblasting. Low resistivity solvents such as ethanol mixed with the normal cleaning solvent results in improved control of charge generation.

7.2.14 Relative humidity. Humid air helps to dissipate electrostatic charges by keeping surfaces moist, therefore increasing surface conductivity. Substantial electrostatic voltage levels can accumulate with a decrease in relative humidity (see table III). However, it is also evident from table III that significant electrostatic voltages can still be generated with relative humidity as high as 90 percent. Relative humidity between 40 percent and 60 percent in ESD protective areas is desirable as long as it does not result in accelerating rust formation or result in other detrimental effects such as PWB delamination during soldering. Where high relative humidity levels cannot be maintained, the use of ionized air should be used to dissipate electrostatic charges.

7.3 Grounding considerations.

7.3.1 General. The safety requirements of MIL-STD-454, Requirement 1 should be considered in the construction of ESD protected areas and at grounded work benches to reduce the chance of electrical shock to personnel.

7.3.1.1 Current rather than voltage is the most important variable in establishing the criterion for shock intensity. Three factors that determine the severity of electrical shock are: (1) magnitude of current flowing through the body; (2) path of current through the body; and (3) duration of time that the current flows through the body. The voltage necessary to produce a fatal current is dependent upon the resistance of the body, contact conditions, and the path through the body (see table VIII).

7.3.1.2 Sufficient current passing through any part of the body will cause severe burns and hemorrhages. However, relatively small currents can be lethal if the path includes a vital part of the body, such as the heart or lungs. Electrical burns are usually produced by heat from the arc which occurs when the body touches a high-voltage circuit. Electrical burns are also caused by passage of electrical current through the skin and tissue. A.C. currents of 4 to 21 milliamperes can cause reflex action. Although not electrically dangerous this could result in other safety hazards to people or equipment.

7.3.1.3 There are various methods of incorporating adequate safeguards for personnel, many of these methods being implicit in routine design procedures.

TABLE VIII. Effects of electrical current on humans
(Ref.: MIL-STD-454)

Current Values (Milliamperes)		Effects
AC 60 Hz	DC	
0-1	0-4	Perception
1-4	4-15	Surprise
4-21	15-80	Reflex action
21-40	80-160	Muscular inhibition
40-100	160-300	Respiratory block
Over 100	Over 300	Usually fatal

7.3.2 Ground potential of electronic test equipment and tools. The design and construction of the ESD protected area and ESD grounded work benches should ensure that all external parts, surfaces, and shields in electronic test equipment and power tools are at a common ground potential at all times during normal operation. The design should include consideration of ground faults and voltage limits established where hazardous voltages or current exist. Any external or interconnecting cable, where a ground is part of the circuit, should carry a ground wire in the cable terminated at both ends in the same manner as the other conductors. In no case, except with coaxial cables, should the shield be depended upon for a current-carrying ground connection. Plugs and convenience outlets for use with metal cased portable tools and equipment should have provisions for automatically grounding the metal frame or case of tools and equipment when the plug is mated with receptacle, and the grounding pin should make first, break last. Cautions should be required in locating such tools and test equipment on grounded work benches with metal or other conductive coverings since the hard case ground of the tool and test equipment grounded cases can shunt the protective resistance in the work bench ground cable. As an added precaution for personnel safety ground fault interrupters should be used with test equipment. The ground fault interrupter senses leakage current from faulty test equipment and interrupts the circuit almost instantaneously when these currents reach a potentially hazardous level. CAUTION MUST BE OBSERVED IN EMPLOYING PARALLEL PATHS TO GROUND THAT COULD REDUCE EQUIVALENT RESISTANCE OF PERSONS TO GROUND TO UNSAFE LEVELS. Personnel movements in conjunction with wrist straps, table tops and floor mats could result in such parallel paths.

7.3.3 Ground potential of grounded work benches. Grounded work benches should be soft grounded to eliminate the safety hazard of touching a high voltage circuit with one hand and a hard ground with the other. A soft ground should incorporate appropriate resistance to limit currents from accessible voltage sources to 5 milliamperes.

7.3.3.1 Grounding materials. Work bench surfaces should be covered with ESD protective materials and grounded. A method for connecting ground cables is as follows:

a. Attach the ESD protective material to the work bench surface with steel screws with approximately 2.5 cm diameter steel flat washers under the screw heads or by means such as double-faced carpet tape with one steel screw and steel washer under the screw head;

b. Connect one terminal of the resistive ground cable between the screw head and the metal washer. Connect the terminal on the other end of the resistive ground cable to earth, power or ship's hull ground;

c. If a melamine laminate is used for the ESD protective table top, the screw for attaching the ground cable should extend into the material layers since the inner layers are more conductive than the finished surface.

7.3.3.2 Grounding considerations. Safety and grounding considerations for ESD protected area and grounded work bench are as follows:

a. Cables and resistors should have ample current carrying capacity. Since the work bench ground is for bleeding off electrostatic charges a half watt resistor is usually sufficient;

b. Ground cable connections should be continuous and permanent;

c. Resistance(s) to ground should be high enough, considering all parallel paths, to limit leakage current to personnel to 5 milliamperes maximum based upon the highest voltage source accessible by grounded personnel. Such voltage sources include power sources and test equipment;

d. The ground cable and connection material should be of sufficient mechanical strength to minimize the possibility of inadvertent ground disconnections. Protection to less than 5 milliamperes may be advisable where reflex action could cause problems;

e. Work bench tops, floor mats, ground straps and other ESD protected area grounds used to discharge static electricity should be connected to earth, power system or other hard ground as appropriate, through current limiting resistances. The wrist strap should be connected to ground through the work bench top ground point (see figure 2). Work benches should not be connected in series with one another because the series resistances are additive resulting in higher ESD dissipation times. Also, opening of one ground cable could affect the opening of other work bench ground cables;

f. Locate resistances in personnel ground straps and work bench tops ground cables as described in 7.2.6.1 and 7.2.8;

g. Electrically connect carriers, holders, or containers together before transferring ESD sensitive parts from one to the other.

7.3.3.2.1 ESD ground resistance considerations. Whereas the safety considerations provide the minimum resistance to ground for protection of personnel, the maximum resistance to hard ground for personnel grounding should be limited by the decay time for an electrostatic charge. This decay time is determined by the human capacitance and resistance and the resistance of other ground paths to hard ground. The decay time should be short enough to dissipate charges at or below the rate at which they are normally generated.

8. OPERATING PROCEDURES

8.1 Organizations affected by ESD controls. An effective ESD control program requires the coordination and integration of various organizations or functions within a facility and a system of checks and balances. Organizations affected generally include:

a. Acquisition

b. Design engineering;

c. Reliability engineering;

d. Quality assurance;

e. Manufacturing

f. Test and field engineering;

g. Packaging and [illegible]

8.1.1 Functions. From a functional standpoint ESD operating procedures apply to:

a. Design and drafting;

b. Inspection;

c. Test;

d. Manufacturing and processing;

e. Assembly;

f. Maintenance, repair and rework;

g. Packaging and marking;

h. Installation;

i. Transportation;

j. Failure analysis.

8.2 General guidelines for handling ESDS items. The following general guidelines are applicable to the handling of ESDS items:

a. People handling ESDS items should be trained in ESD precautionary procedures, tested for competency and certified. Untrained personnel should not be allowed to handle ESDS items when the items are outside of the ESD protective packaging;

b. When not actively working with ESDS items, using the terminals for testing, or inserting the terminals of a part in a PWB or assembly electrical socket, shunts such as bars, clips, or non-corrosive conductive foam or protective covering should be used to protect the item from triboelectric generation, direct discharge, electrostatic fields and EMP from high voltage ESD spark discharge. When inserting part leads into PWB terminal holes or making connections to part leads, shorting bars, clips or conductive foam should be inserted over the connector terminals at the PWB or higher assembly level. For protection from electrostatic fields and EMP from high voltage ESD spark discharge, conductive outer wrapping should be used, especially when being transported outside of ESD protected areas;

c. People maintaining ESDS equipment where personnel ground straps cannot be used should ground themselves prior to removing ESDS items from their protective packaging. When being handled out of their protective packaging, ESDS items should be handled by the shunting device, without touching ESDS parts or electrical runs;

d. The leads or connector terminals of ESDS items should not be probed by multimeters (VOM). If this is not practical, touch ground with the electrical test equipment probes before probing the ESDS item;

e. Tools and test equipment used in ESD protective areas should be properly grounded; hand tools should not contain insulation on the handles or if used, tools with insulated handles should be treated with a topical antistat;

f. Power should not be applied to equipment or assemblies while ESDS items, especially those containing MOS devices, are being removed or inserted. Additional precautions for MOS are as follows:

(1) Signals should not be applied to the inputs while MOS device power is off;

(2) When testing MOS, all unused input leads should be connected to either source ground or V_{SS} or supply, V_{DD}, whichever is appropriate for the circuit involved;

(3) Prior to performance of dielectric or insulation resistance tests, MOS should be removed from the equipment;

(4) Check all power supplies used for testing ESDS items to assure there are no voltage transients present;

(5) Check test equipment for proper voltage polarity before conducting parameter or functional testing;

g. Assure that all containers, tools, test equipment, and fixtures used in ESD protective areas are grounded before and during use either directly or by contacting with a grounded surface. Grounding of electrical test equipment should be via a grounded plug, not through the conductive surface of the ESD grounded work station;

h. Electrically connect carriers, holders or containers together before transferring ESDS parts from one to the other;

i. Work instructions, test procedures, drawings and similar documents used in ESD protected areas should not be covered in common plastic sheeting or containers;

j. Drawings for ESDS items should be marked with the ESD sensitive electronic symbol, warnings, precautions, and handling procedures as applicable;

k. Manufacturing, process, assembly and inspection work instructions should identify ESDS items as needed for ESDS control and require that such items be handled out of their ESD protective packaging only by trained personnel and only in ESD protected areas;

l. Personnel handling ESDS items should avoid physical activities which are static producing in the vicinity of ESDS items. Such activities include wiping feet and removing or putting on smocks;

m. Personnel handling ESDS items should wear ESD protective clothing (see table II). Such clothing should be monitored periodically with static meters. Close-fitting, short sleeved "street" garments are acceptable for ESD purposes provided they do not contact ESD items directly. Common synthetic clothing should be regarded as a static hazard and work habits should be developed to prevent its contact with ESDS items. Gloves and finger cots, if used, should be made of ESD protective material;

n. Periodic continuity and resistivity checks of personnel ground straps between skin contact point and ground connection, ESD grounded work bench surfaces, conductive floor mats and other connections to ground should be performed periodically with suitable test equipment such as a megohmmeter to assure conformance to grounding resistivity requirements;

o. Neutralize charges of ESD protective packaging containing an ESDS item by placing the packaged item on an ESD grounded work bench surface to remove any charge prior to opening the packaging material. Alternately, charges can be removed by grounded personnel touching the package;

p. Remove ESDS items from ESD protective packaging using finger or metal grasping tool only after grounding and then place on the ESD grounded work bench surface;

q. When testing ESDS items in test chambers using carbon dioxide or nitrogen gas for cooling, the chamber should be equipped with grounded baffles and shelves, on which equipment rests, that are grounded to dissipate electrostatic charges created by the flow of the gas. In-line ionizers for the gas are needed when the chambers or ESDS items have insulating surfaces;

r. When ESDS items are manually cleaned with brushes, only brushes with natural bristles should be used and ionized air should be directed over the cleaning area to dissipate any static charges. All automatic cleaning equipment should be grounded if practicable and leads and connectors of ESDS items should be shorted together during the cleaning operation. Conductive cleaning solvents should be used where practicable when cleaning ESDS items;

s. Caution should be observed in using solvents such as acetone and alcohol or other cleaning agents for cleaning ESD protective materials. The use of such solvents can reduce the effectiveness of some ESD protective materials, especially those employing detergent type antistats which bleed to the surface to form a sweat layer with moisture in the air;

t. The cases or chassis grounds of test equipment and ESDS items being tested should be electrically connected together prior to connecting or disconnecting any test cables. When connecting test cables, shunting bars should remain in place until chassis grounds are shorted. Shunting bars should be replaced upon removal of test cables.

8.3 Sample operating procedures.

8.3.1 Acquisition. Procedures are as follows:

a. Incorporate ESD control program requirements on all acquisitions related to design and handling of ESDS items;

b. Work with quality assurance to ensure subcontractors and suppliers comply with ESD control program requirements;

c. Maintain listing of supply sources of ESD protection equipment and materials.

8.3.2 Design engineering. Procedures are as follows:

a. Identify all items recommended for use in the design that are ESDS and their sensitivity levels;

b. Select parts that offer the greatest immunity from ESD consistent with meeting performance requirements. For example, if MOS devices are used, select those which include maximum internal protection;

c. Design protection circuitry into assemblies. Implement protective circuitry at the lowest practical level of assembly;

d. Perform circuit analysis to determine whether assemblies containing ESDS parts are adequately protected;

e. Ensure parts and assembly drawings and other related engineering documentation include ESD markings as follows:

(1) The MIL-STD-129 sensitive electronic device symbol;

(2) The ESD caution marking:

"CAUTION -- ELECTROSTATIC SENSITIVE DEVICE: Remove electrostatic protection at use or in protected area. Reuse packaging materials for the unserviceable item. See DOD-HDBK-263 for protective handling or testing measures for this item."

(3) Applicable special ESD handling, packaging and labeling requirements or reference to existing documented procedures;

(4) Directions for marking ESDS assemblies with the MIL-STD-129 ESD sensitive electronic device symbol. Marking of the ESDS assembly should be visible when the item is installed in its next higher assembly;

f. Ensure equipment and cabinet level drawings contain:

(1) The MIL-STD-129 sensitive electronic device symbol if ESDS item(s) are contained therein;

(2) Directions for labeling equipment cabinet containing ESDS items with the MIL-STD-129 symbol and caution as follows:

> "CAUTION -- THIS EQUIPMENT CONTAINS PARTS SENSITIVE TO DAMAGE BY ELECTROSTATIC DISCHARGE (ESD). USE ESD PRECAUTIONARY PROCEDURES WHEN TOUCHING, REMOVING OR INSERTING PARTS OR ASSEMBLIES."

g. Assist in failure analysis and implementation of corrective action;

h. Present design considerations and conformance to ESD requirements at all design reviews.

8.3.3 Reliability. Procedures are as follows:

a. Review parts list to identify ESDS items, determine ESDS sensitivity levels, maintain ESDS parts data for use by Design Engineering;

b. Perform ESD testing;

c. Work with Design to detect and classify possible ESD related failures or degraded performance;

d. Analyze production and field information to detect possible ESD related failures or degraded performance;

e. Be alert to part performance degradation due to ESD related latent failures;

f. Ensure ESD design requirements are adequately implemented in the hardware design;

g. Ensure failure analysis properly considers ESD failure modes.

8.3.4 Quality Assurance. Procedures are as follows:

8.3.4.1 Quality control.

a. Determine the requirements for the establishment of protected areas and grounded work benches. Certify the adequacy of protected areas and grounded work benches prior to their use. Document certification test procedures and data;

b. Ensure the use of protective personnel clothing and proper personnel grounding at all necessary points where ESDS items are handled outside their protective packaging;

c. Establish and conduct training programs to ensure all personnel handling ESDS items have received the necessary training and proficiency;

d. Perform monthly audits to assure the integrity of the ESD protected areas and ESD grounded work benches, personnel grounding facilities, grounding of tools and test equipment and the implementation of the handling, packaging and labeling procedures. Audits should be performed with electrostatic fieldmeters to assure that the ESD materials and equipment are maintaining their effectiveness;

e. Verify that all drawings and all assembly, test, inspection, packaging and handling work instructions contain ESD markings, precautions and handling procedures as appropriate;

f. Inspect ESDS items for proper ESD markings;

g. Assure acquisition documentation includes ESD program requirements as applicable;

h. Perform audits and surveys of subcontractor and supplier ESD control programs.

8.3.4.2 Receiving inspection. Procedures are as follows;

a. Be aware of all ESDS items to be delivered by vendors;

b. Remove the unit package of an ESDS item from the shipping container. Do not open unit package. Examine the item for proper labeling and ESD protective packaging in accordance with the procedure or contract. Inspect as follows:

(1) Labeled packages - packages of ESDS items should be examined to verify conformance to the precautionary labeling and ESD protective packaging requirements of the contract;

(2) Non-ESDS marked packages - while the supplier is responsible for proper marking of packages containing ESDS items, the treatment of such items delivered without an ESDS marking should be governed as follows:

(a) No ESDS marking, but in protective packaging - the packaging should be marked with proper markings and these ESDS items should be handled in accordance with the procedures of this document. The supplier should be reminded to ensure proper marking of future shipments;

(b) No ESD marking, and no ESD protective packaging - the ESDS item should be rejected as defective and should not be accepted if resubmitted by the supplier;

(3) Open unit packaging and perform tests of ESDS items only in a protected area and if size permits at an ESD grounded work bench. Follow the handling guidelines of 8.2;

(4) Repackage tested ESDS items in ESD protective packaging material and assure proper marking on the packaging;

(5) Place unit packages in ESD protective tote boxes or trays for transporting to stores.

8.3.4.3 In-process inspection and test. Procedures are as follows:

a. Observe the handling guidelines of 8.2;

b. Open unit packaging of ESDS items only in protected areas at grounded work benches;

c. After examination and test, repackage ESDS assemblies in ESD protective packaging materials and ensure proper marking on unit packaging. Place ESDS assemblies in protective tote boxes or trays for transporting to next work bench;

8.3.4.4 Failure analysis laboratory. Procedures are as follows:

a. Determine that all ESDS items received for failure analysis are properly packaged in ESD protective packaging material. If such items are not properly packaged, notify the sender of the item to prevent future unprotected failure analysis submittals;

b. Perform failure analysis of ESDS items, observing the handling guidelines of 8.2;

c. Direct a stream of ionized air over the work area until there is no apparent residual voltage as measured by a static meter if shunting bars, wrist straps or other protective procedures cannot be used;

d. Replace shunting bars, clips or foam; repackage the ESDS item in ESD protective packaging material; and ensure proper marking on unit packaging. Place unit packaging in tote boxes or trays in storage when ESDS items or sections thereof are to be saved for future analysis.

8.3.5 Manufacturing.

8.3.5.1 Production and factory services. Procedures are as follows:

a. Design and construct protected areas and grounded work benches;

b. Work with Quality Control to implement and maintain production procedures and measures.

c. Investigate possible ESD related failure trends and problem areas occurring during production with Reliability and Quality Control.

8.3.5.2 Material receiving area. Procedures are as follows:

a. Be aware of all ESDS items to be delivered by vendors;

b. Do not open packages containing ESDS items. Perform quantity counts of ESDS items to compare with contract quantities. If protective packaging is opaque or if counts cannot be verified without opening ESD protective packaging, quantity counts shall be deferred to Receiving Inspection.

8.3.5.3 Storeroom area. Procedures are as follows:

a. Transport ESDS items to and from the stockroom area in ESD protective packaging and tote boxes or trays which will protect the ESDS items from triboelectric charges, discharges from personnel or objects, electrostatic fields and EMP from ESD high voltage spark discharge;

b. Do not open unit packages of ESDS items for count issuance or kitting unless required. When required, opening of unit packaging of ESDS items should be performed at grounded work benches observing the handling guidelines of 8.2. Repackage ESDS items in ESD protective packaging, and mark packaging with the MIL-STD-129 sensitive electronic device symbol and caution;

c. Ensure all packages and kits issued from the stockroom containing ESDS items are marked with the ESD sensitive symbol and precautions;

d. Identify ESDS items on all kitting documentation.

8.3.5.4 Production, processing, assembly, repair and rework. Procedures are as follows:

a. Perform operations only in protected areas and where practicable at ESD grounded work benches;

b. Use static eliminators or ionized air blowers to direct a stream of ionized air over the ESDS item being processed when grounding techniques cannot be used to equalize or dissipate electrostatic charges;

c. Perform cleaning processes using conductive cleaning fluids or solvents. Where solvents are air sprayed use ionized air;

d. Upon completion of assembling and processing of the ESDS assembly, repackage in ESD protective packaging material and assure proper marking. Place the ESDS assemblies in protective tote boxes or trays for transporting to next work bench.

8.3.6 System and equipment level test and maintenance. The following procedures also apply to testing in the field:

a. Perform testing of ESDS items only in ESD protected areas to the extent practicable;

b. Observe handling guidelines of 8.2 and the following:

(1) Perform diagnostics to isolate the faulty assembly. Do not use canned coolant for fault isolation;

(2) Shut off power to equipment;

(3) Prior to touching an ESDS item, attach personnel ground strap to wrist and connect the other end to the equipment cabinet or chassis ground. Where personnel ground straps cannot be used touch the grounded equipment chassis with a hand prior to removing or inserting an ESDS item;

(4) Upon removal of the failed ESDS item, package in ESD protective packaging material;

(5) Do not probe or test ESDS items with a test equipment lead unless necessary and ideally, under controlled conditions such as with ionized air. When such probing is necessary, ground the meter and probes or test leads prior to touching the terminals of the ESDS item;

(6) Ground the ESD protective package containing the replacement ESDS item to the equipment chassis prior to opening to dissipate any accumulated charge on the package;

(7) Open package at the connector end if possible. Remove the ESDS item from the ESD protective packaging and install the item in the equipment. Avoid touching parts, electrical terminals, and circuitry;

(8) Perform all other required maintenance actions such as tightening of fasteners, adjustments and replacement of covers prior to removal of the personnel ground strap. If a ground strap is not worn, touch the grounded equipment chassis prior to each action;

(9) Energize equipment and verify correction of fault.

8.3.7 Packaging and shipping. Procedures are as follows:

a. Ensure all ESDS items submitted for shipment have been received in ESD protective packaging material;

b. Remove items from interim packaging only at an ESD grounded work bench, observing the handling guidelines of 8.2;

c. Package the ESDS item in ESD protective material for shipment as required by the contract.

9. DESIGN OF PROTECTION NETWORKS

9.1 General. Various protection networks have been developed to protect sensitive MOS. These circuit protection networks provide limited protection against ESD. Many of the protection networks designed into MOS devices reduce the susceptibility to ESD to a maximum of 800 volts. MIL-M-38510 V-ZAP test voltages for CMOS, for example, vary from 150 to 800 volts. Protection circuitry of some devices is improving and protection to 4,000 volts appears to be achievable for some MOS devices. However, electrostatic potentials of tens of thousands of volts can be generated in uncontrolled environments.

9.1.1 The protection afforded by specific protection circuitry is limited to a maximum voltage and a minimum pulse width. ESDs beyond these limits can subject the part's constituents to damage or damage the protection circuitry constituents themselves which are also often made of moderately or marginally sensitive ESDS parts. Damage to the protection circuitry constituents could result in degradation in part performance or make the ESDS part more susceptible to subsequent ESDs. The degradation, for example, could be a change in speed characteristics of the ESDS part or an increase in leakage current of the ESDS part. Multiple ESDs at voltages below the single ESD pulse sensitivity voltage or energy level can also weaken or cause failure of the part performance or protection circuitry constituents resulting in degradation or failure of the ESDS part. Loss of protective circuitry may not be apparent after an ESD.

9.1.2 In summary, protection networks reduce but do not eliminate the susceptibility of a part to ESD. This reduction in ESD sensitivity, however, results in a lower incidence of ESD part failure.

9.1.3 The sensitivity of the same type of ESDS part can vary from manufacturer to manufacturer. Similarly, the design and the effectiveness of protection circuitry also varies from manufacturer to manufacturer.

9.2 Design precautions. Various design techniques have been employed in reducing the susceptibility of parts and assemblies to ESD. Diffused resistors and limiting resistors provide some protection, but are limited in the amount of voltage they can handle. Zeners require greater than 5 nanoseconds to switch and may not be fast enough to protect an MOS gate. Furthermore, zener schemes, diffused resistors and limiting resistors reduce the performance characteristics of the part which in many instances are the primary considerations for which that part was designed.

9.2.1 Parts and hybrids design considerations. Some design rules to reduce ESD sensitivity for parts and hybrids are as follows:

a. MOS protection circuitry improvement techniques are: increasing diode size; using diodes of both polarities; adding series resistors; and utilizing a distributed network effect;

b. Avoid cross-unders beneath metal leads connected to external pins; otherwise treat the part as electrostatic sensitive. Also, since cross-unders are diffused during the N+ (emitter) diffusion process, the oxide over the diffusion will be thinner, causing this area to have a lower dielectric breakdown. Deep N diffusions, rather than N+ diffusions, should be used for cross-unders, if a deep N diffusion step is used in the fabrication process;

c. MOS protection circuits should be examined to see if the layout permits the protection diodes to be defective or blown without causing the circuit to be inoperative;

d. Distance between any contact edge and the junction should be 70 microns or greater on bipolar parts;

e. Linear IC capacitors should be paralleled by a PN junction with sufficiently low breakdown voltage;

f. For bipolar parts avoid designs permitting a high transient energy density to exist in a PN junction depletion region under ESD. Use series resistance to limit ESD current or use parallel elements to divert current from critical elements. The addition of clamp diodes between a vulnerable lead and one or more power supply leads can improve ESD resistance by keeping critical junctions out of reverse breakdown. If a junction cannot be kept out of reverse breakdown, physically enlarging the junction will make it more ESD resistant by reducing the initial transient energy density in inverse proportion to its area;

g. The protection of a transistor from ESD can be improved by increasing the emitter perimeter adjacent to the base contact. This lowers transient energy density in the critical emitter sidewall. Enlarging the emitter diffusion area also helps in some pulse configurations;

h. As an alternative to using clamping diodes, which consume chip area and can cause unwanted parasitic effects, a "phantom emitter" transistor can be used to improve ESD resistance. The phantom transistor incorporates a second emitter diffusion shorted to the base contact. This creates a deliberate separation of the base contact from the normal emitter without interfering with normal transistor operation. The second emitter provides a lower breakdown path BV_{CEO} between the buried collector and the base contact;

i. Avoid pin layouts which put the critical ESD paths on corner pins which are prone to ESD;

j. Avoid metallization cross-overs where possible. These cross-over areas are typically separated by thin dielectric layers. Cross-overs often impose a number of metallurgical requirements which are frequently incompatible. For example, once the first metallization layer (Al) is deposited, the circuit cannot be subsequently heated in excess of 550°C because the eutectic point of Al-Si system is 575°C. Thus, the dielectric layer (SiO_2) should be deposited by a low temperature process such as pyrolytic deposition. This layer is prone to breakdown from ESD for two reasons:

(1) A low temperature growth of SiO_2 generally is not uniform in thickness and not free from pin holes;

(2) The dielectric layer is thin and thus the breakdown voltage is very low;

k. Avoid parasitic MOS capacitors whenever possible. Microcircuits with metallization crossing over low resistance active regions, that is, V_{CC} over N+ isolated diffusions, are moderately sensitive to ESD. Such constructions include microcircuits with metallization paths over N+ guard rings. N+ guard rings are used in the N-type epitaxial islands to inhibit possible inversion of the N-type semiconductor to P-type semiconductor and to reduce the leakage current. Since the final oxide layer over the N+ guard ring is relatively thin, parasitic MOS capacitors of relatively low breakdown voltage are created when a metallization path passes over this ring. These MOS capacitor structures are ESDS as indicated in table V;

l. Caution is advised in the use of microcircuits and hybrids containing dielectrically isolated bipolar parts which are generally moderately sensitive to ESD. Failure occurs due to breakdown of the thin dielectric layers between these small geometry bipolar parts from an ESD.

9.2.2 Assembly design considerations. Procedures are as follows:

a. Latchup in CMOS, with the exception of analog switches, can be avoided by limiting output current. One solution is to isolate each output from its cable line with a resistor and clamp the lines to V_{DD} and VSS with two high speed switching diodes. The use of long input cables poses the possibility of noise pickup. In such cases filter networks should be used;

b. Additional protection can be obtained for MOS by adding external series resistors to each input;

c. Where practicable, an RC network consisting of a relatively large value resistor and a capacitor of at least 100 pF should be used for sensitive inputs on bipolar parts to reduce effects from ESD. However, if circuit performance dictates, two parallel diodes clamping to a half volt in either polarity can be used to shunt the input to ground. This reduces disturbances to the input characteristics;

d. Leads of sensitive parts mounted on PWBs should not be connected directly to connector terminals without series resistance, shunts, clamps or other protective means. Assembly designs containing ESDS items should be reviewed for incorporation of protective circuitry;

e. Systems incorporating keyboards, control panels, manual controls, or key locks should be designed to dissipate personnel static charges directly to chassis ground, bypassing ESDS parts.

9.3 ESDS part protection networks. Manufacturers have incorporated protection circuitry on most MOS devices (see figure 3). The purpose of these protection networks is to reduce the voltage across the gate oxide below the dielectric breakdown voltage without interfering with part electrical performance. Differences in fabrication processes, design philosophies and circuitry have resulted in different gate protection networks.

10. PERSONNEL TRAINING AND CERTIFICATION

10.1 General. Training in ESD awareness should be provided to all people who specify, procure, design, or handle ESDS items. The most extensive ESD protected manufacturing areas and ESD protective handling procedures will not provide the protection needed if people are not properly trained in their correct use. ESD training programs should be oriented to the contractor's facilities and the types of ESD materials and equipment that he has found to be effective for his particular application. Such people should be trained to effectively employ the ESD protective materials and equipment provided, and to understand the theory behind many of the ESD precautions included in ESD handling procedures to effect their use. Personnel should be trained in grounding safety precautions. ESD awareness should also be a part of equipment training courses prepared by contractors for the user. Such training should include identification of ESDS items in the equipment, some basic ESD theory, ESD handling precautions, the need for, use of and types of ESD protective packaging and the safety aspects involved where grounding is a part of the ESD handling procedures.

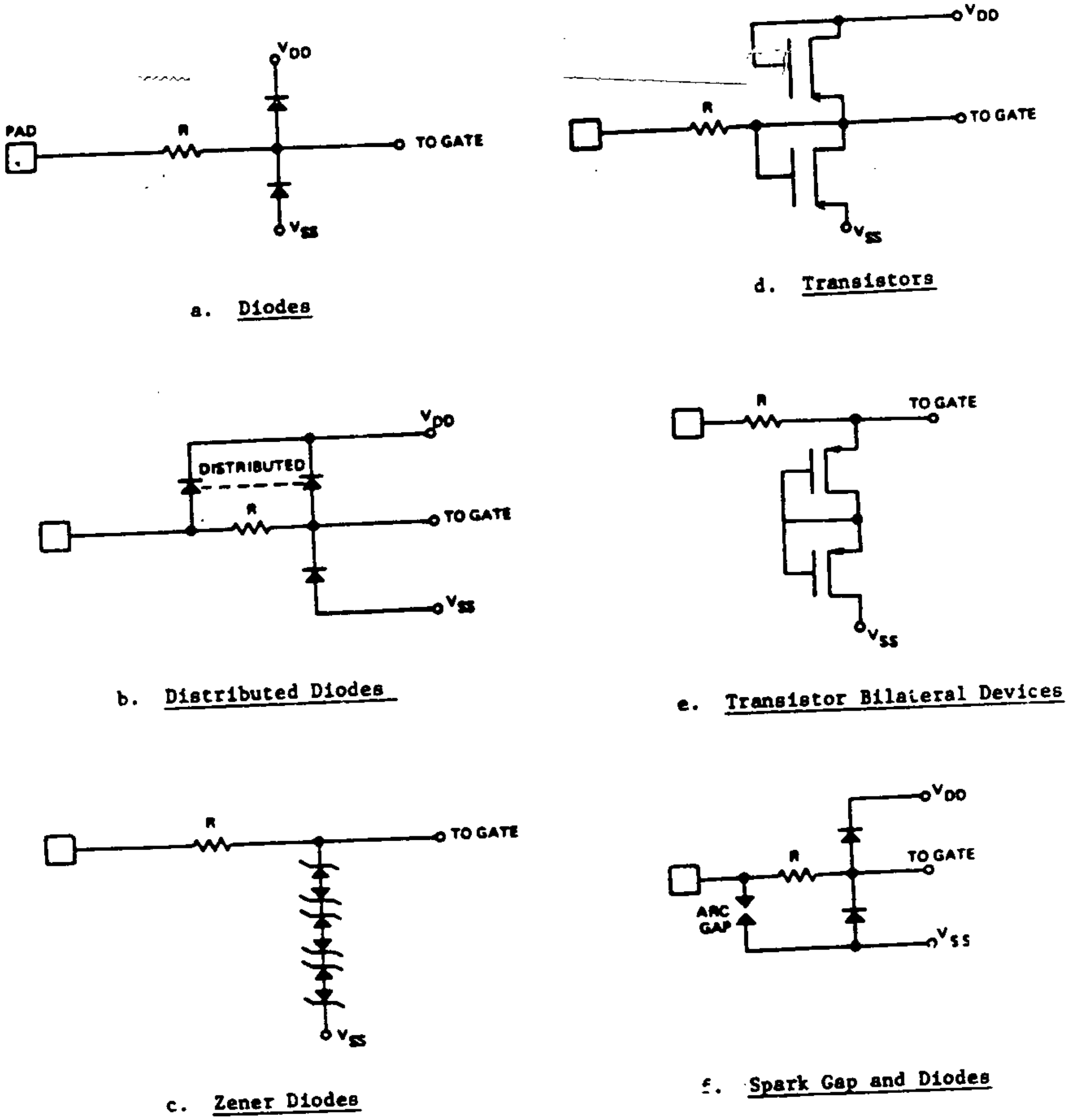

FIGURE 3. Gate protection networks

10.1.1 The skill level of the trainees also has a bearing on the ESD training to be given. The depth of theory on static electricity should depend on the trainee's ability and need to comprehend the depth of information provided. For example, engineers require more theoretical training for design of protective circuitry than stock room personnel need for kitting ESDS items. Certification of satisfactory completion of the training course should be documented for people who have attended and demonstrated a comprehension of the elements of the training course. Guidelines for tailoring ESD training courses for various types of people are shown in table IX for the ESD course outline described in 10.2.

10.2 Course outline. A comprehensive ESD training course could include the following:

A. ESD control program (Reference DOD-STD-1686)
   1. Organization and responsibility
   2. Program requirements
B. Principles of static electricity
   1. Definition of static electricity
   2. Causes
   3. Prime electrostatic generators
   4. Triboelectric generation, electrostatic fields and ESD high voltage spark discharge induced EMP
   5. Control methods
      a. Grounding
      b. Protective handling
      c. ESD protective materials
      d. Topical antistats
      e. ESD protective equipment
      f. High humidity
      g. Ionized air
C. Electrical and electronic ESDS items
   1. Definition of ESDS items
   2. How ESDS items are damaged or destroyed
   3. Listing of ESDS part types and parts
   4. ESDS part voltage sensitivity levels
   5. ESD classification techniques
D. ESD protective materials and equipment
   1. ESD protective materials
      a. Types such as conductive, static dissipative, and anti-static
      b. Application considerations
   2. Formed shapes of ESD protective materials
      a. Work bench coverings or pads
      b. Tote boxes, trays, vials, bags, carriers, etc.
      c. Floors, floor mats
   3. Protective personnel apparel
      a. Smocks, gauntlets, gloves, finger cots
      b. Topical anti-static treatment of garments
      c. Conductive shoes, shoe covers, heel grounders
      d. Personnel ground straps such as wrist, ankle, or leg

TABLE IX. ESD training guidelines

Type of Personnel	A ESD Control Program	B Principles of Static Electricity	C Electrical and Electronic ESDS Items	D ESD Protective Materials and Equipment	E Protected Areas/Grounded Work Benches	F ESD in Design	G Failure Analysis Techniques	H Handling Precautions and Procedures	I Packaging and Shipping of ESDS Items
	Training Course Outline Section								
Program Manager	X	X							
Engineering	X	X	X	X	X	X	X	X	X
Acquisition Personnel	X	X	X	X					X
Quality Control Personnel	X	X	X	X	X	X	X	X	X
Field Engineer, Installation and Maintenance		X	X	X	X			X	X
Production Operators and Technicians		X	X	X	X			X	X
Stockroom and Kitting Personnel		X	X	X	X			X	X

4. Shorting bars, clips, conductive foams
5. Protective equipment
   a. Grounded work bench surfaces
   b. Grounded test equipment, power tools
   c. Grounded solder iron tips, solder pots, flow soldering equipment
   d. Grounded chairs and stools
   e. Metallized solder suckers
   f. Ionizers
   g. Static alarm systems, detectors and meters

E. Protected areas and grounded work benches
   1. Design and construction
   2. Prohibitions such as common plastics, synthetics, and other static generators, personnel movements to avoid, and cleaning solutions to avoid
   3. Grounding
      a. Techniques
      b. Grounding safety precautions
   4. Monitoring with electrostatic voltmeters, ohmmeters and meggers

F. ESD in design
   1. Considerations in parts selection
   2. Protective circuitry objectives and techniques

G. Failure analysis techniques

H. Handling precautions and procedure

I. Packaging and shipping of ESDS items

10.3 Training aids. Training aids suggested for use in ESD training programs include:

A. Movie: ZAP! STATIC AWARENESS, No. 35407DN, 25 minutes, 16 mm and 1.9 cm video tape cassette, color and sound (available from Navy film libraries to government personnel).

B. Samples
   1. ESD sensitivity symbols
      a. MIL-STD-129
      b. Industrial symbols
   2. ESD protective materials
   3. ESD protective tools and equipment

C. Electrostatic voltmeter, field meter, ohmmeter, megger

D. Other visual aids such as vu-graphs, diagrams of grounded work stations, pictures and brochures of ESD protective tools and equipment, and photographs of damaged ESDS items.

11. CERTIFICATION AND MONITORING OF PROTECTED AREAS AND GROUNDED WORK BENCHES. Certification and monitoring of ESD protected areas and

grounded work benches should consider the following:

a. The use of ESD protective materials wherever ESDS items normally come in close proximity or have direct contact such as table tops, parts trays, bins, carriers, carts, tote boxes, packaging material, clothing and work stools (see 7.1);

b. The incorporation of personnel grounding system such as personnel ground straps or alternate grounding system consisting of protective flooring, grounded work stools, and conductive shoes (see 7.2.6);

c. The incorporation of grounding systems for processing machinery or the use of ionizers where grounding cannot be implemented (see 7.2.10 through 7.2.13);

d. The ability of grounding to reduce residual electrostatic voltages below the sensitivity level of ESDS items being handled (see 7.3);

e. Absence of prime generators in the ESD protected areas or near ESD protected work benches at least 1 meter away from ESDS items;

f. The grounding of power tools such as soldering irons, solder pots and test equipment used at ESD grounded work benches (see 7.2.10);

g. Availability of protective personnel apparel for use in protected areas including conductive shoes or heel grounders where conductive floors are used (see 7.2.7);

h. Resistance measurements of all ground with ohmmeters or meggers to assure that resistances are low enough to limit residual ESD voltages and high enough to protect personnel from nearby voltage sources;

i. Effectiveness of the ESD protected area and grounded work benches to limit electrostatic voltages to safe levels by checking with electrostatic field or volt meters or static detectors;

j. Effectiveness of ESD protective equipment such as ionizers, built-in detectors and alarms, and humidity control where used.

12. BIBLIOGRAPHY. The following list of reference documents is provided for further information relating to electrostatics and the elements of an ESD control program. These references are listed under the following categories:

a. General information on electrostatics or ESD control programs;

b. ESDS part information such as identification of ESDS parts, ESDS part sensitivity, failure modes, mechanisms, failure analysis techniques, ESD testing and ESD protective circuitry;

c. ESD protective materials and equipment information, data on design and construction of ESD protected areas; and ESD precautionary methods and controls for handling and packaging of ESDS items.

12.1 General information on electrostatics and ESD control program.

a. "Electrical Overstress/Electrostatic Discharge Symposium Proceedings," EOS-1, Reliability Analysis Center, 1979;

b. EOS/ESD Technology Abstracts, Reliability Analysis Center, Catalog Number TRS-3;

c. Freeman, E.R., and Beall, J.R., "Control Electrostatic Discharge Damage to Semiconductors", IEEE Proceedings, 12th Annual Reliability Physics Symposium, 1974;

d. Gaspard, K.R., "Understanding and Controlling Electrostatic Discharge", Honeywell Avionics and Defense Systems Components Comments, No. 175, 13 February, 1978;

e. Grimmet, C., "Removal of Conformal Coatings by Abrasive Blasting", GIDEP Document Summary Sheet R4-F-78-01, Hughes Aircraft Company, January 1978;

f. Jowett, C.E., "Static Electrification Hazards in Microelectronics Production," Microelectronics and Reliability, Vol. 13, 1974, Great Britain;

g. Kirk, Jr., W.J., Carter, L.S. and Waddel, M.L., "Eliminate Static Damage to Circuitry", Electronic Design, March 29 1976;

h. Lyons, D., "Protect Your MOS for Better Reliability", Quality, Management and Engineering", April 1973;

i. McAteer, Owen J., "Shocking Blow to Military Electronics", Military Electronics/Countermeasurers, June 1979;

j. Meyers, S., "A Total Approach to Electrostatic Protection in the Products Environment," Packaging, Handling and Transport Symposium, Defense Preparedness Association;

k. Moore, A.D., "Electrostatics and its Applications," John Wiley and Sons, 1973;

l. Mykkanen, F.C., "ESD Electrostatic Discharge Control, Update No. 1," Honeywell Avionics and Defense Systems Components Comments No. 183, 7 September 1979;

m. Rose, E., "Static Can Cause Bipolar IC Failures", Evaluation Engineering, May/June 1971;

n. Speakman, T.S., "A Model for Failure of Bipolar Silicon Integrated Circuits Subjected to Electrostatic Discharge," IEEE Proceedings, 12th Annual Reliability Physics, 1974;

o. Trigonis, A.C., "Electrostatic Discharge in Microcircuits," IEEE Proceedings, Reliability and Maintainability Symposium, 1976;

12.2 ESDS parts information.

a. Bhatti, I.S., Fuller, E., and Jo., F.B., "VMOS Electrostatic Protection," IEEE Proceedings, 16th Annual Reliability Physics, 1978;

b. Brown, W.O., "Semiconductor Device Degradation by High Amplitude Current Pulses," IEEE Transactions Nuc. Sci. Vol. NS-19 No. 6, 6 December 1972;

c. Gallace, L.J. and Pujol, H.L., "The Evaluation of CMOS Static-Charge Protection Networks and Failure Mechanisms Associated with Overstress Conditions as Related to Device Life," IEEE Proceedings, Reliability Physics Symposium, 1977;

d. Gallace, L.J., and Pujol, H.L., "Reliability of CMOS Integrated Circuits", Computer Magazine, October 1978;

e. Hickernell, F.S.,and Crawford, J.J., "Voltage Breakdown Characteristics of Close Spaced Aluminum Arc Gap Structure on Oxidized Silicon, IEEE 15th Annual Reliability Physics Proceedings, 1977;

f. Hickernell, F.S., Klein, R.S., and Ware, M.R., Arc Gap Input for CMOS LSI Circuitry", Proceedings of the 1976 GOMAC Conference, November, 1976;

g. Hickernell, F.S., "DC Voltage Effects on SAW Device Interdigital Electrodes", IEEE Proceedings of the 15th Annual Reliability Physics, 1977;

h. Himmel, R.P., "The Effect of Static Electricity on Thick Film Resistors", Insulation/Circuits Magazine, September 1972;

i. Himmel, R.P., "Thick Film Resistor Adjustment by High Voltage Discharge," Proceedings, Electronics Components, Conference, 1971;

j. Ho, R., "Electrostatic Effects on Film Resistors", Insulation/Circuits, April 1971;

k. Huang, C.L., et al, "Reliability Aspects of 0.5 µm and 1.0 µm Gate Low Noise GaAs FETs," IEEE Proceedings, 17th Annual Reliability Physics, 1979;

l. Kroeger, J., "Heed the Limitations of MOS I/O Circuitry and You'll Avoid Electrostatic Damage to ICs and Eliminate Noise Problems and Excessive Power Dissipation," Electronic Design, May 10, 1974;

m. Lenzlinger, M., "Gate Protection of MIS Devices," IEEE Transactions on Electron Devices, Vol. ED-18, No. 4, April 1971;

n. Linholm, W. and Plachy, F., "Electrostatic Gate Protection Using an ARC Gap Device", IEEE Proceeding, 11th Reliability Physics Symposium, 1973;

o. Madzy, T.M., "FET Circuit Destruction Caused by Electrostatic Discharge", IEEE Transactions on Electron Devices, September 1976;

p. McAteer, O.J., "Electrostatic Damage in Hybrid Assemblies", IEEE Proceedings of Annual Reliability and Maintainability Symposium, 1978;

q. Pakulsi, E.J. and Touw, T.R., "Electric Discharge Trimming of Glaze Resistors", Proceedings, Hybrid Microelectronics Symposium, 1968;

r. Pancholy, R.K., "Gate Protection for CMOS/SOS," IEEE Proceedings, 15th Annual Reliability Physics, 1977;

s. Schreier, L.A., "Electrostatic Damage Susceptibility of Semiconductor Devices", IEEE Proceedings, 16th Annual Reliability Symposium, April 1978;

t. Smith, Jack S., "Electrical Overstress Failure Analysis in Microcircuits," IEEE Proceedings, 16th Annual Reliability Physics, 1976;

u. Tasca, D.M., "Pulse Power Failure Modes in Semiconductors", IEEE Transactions on Nuclear Science, Vol. NS-15, No. 6;

v. Woods, M.N. and Gear, G., "A New Electrostatic Discharge Failure Mode", IEEE Proceedings, 16th Annual Reliability Physics Symposium, April 1978;

w. Wunch, D.C., "The Application of Electrical Overstress Models to Gate Protective Networks", IEEE 16th Annual Proceedings, Reliability Physics, 1978;

x. Wunch D.C. and Bell R.R., "Determination of Threshhold Failure Levels of Semiconductor Diodes and Transistors Due to Pulse Voltages," IEEE Transactions NS-15, No. 6, December 1968;

12.3 ESD protective materials, equipment and protected areas.

a. Dorcas, D.S. and Scott, R.N., "Instrumentation for Measuring the dc Conductivity of Very High Resistivity Materials", The Review of Scientific Instruments, Vol. 35, No. 9 Canada, September 1964;

b. NAVSEA OD 46363, "Requirements for the Electrostatic Discharge of Electronic Components and Assemblies," Naval Sea Systems Command, 21 March 1977;

c. "Pan-Am Standard Analytical Method No. 6-703, Measurement of Electrostatic Potential Formation on Materials", GIDEP Report D83-D7182, NASA/KSC;

d. Technical Support Package, "Safe Handling Practices for Electrostatic Sensitive Devices", NASA Tech Briefs, Vol. 2, No. 3, MSC-16642, Fall 1977.

Custodians:
Army - ER
Navy - SH
Air Force - 17

Review Activities:
Army - AT, CR, MI
Navy - AS, EC, OS
Air Force - 11, 15, 18, 19, 99

User Activities:
Army - AR, SM
Navy - MC, SA

Preparing Activity:

NAVY-SH
(Project RELI-0012)

☆U.S. GOVERNMENT PRINTING OFFICE: 1982-605-034/5653