SEMI S22-0706b
SAFETY GUIDELINE FOR THE ELECTRICAL DESIGN OF SEMICONDUCTOR MANUFACTURING EQUIPMENT

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NOTICE: Paragraphs entitled "NOTE" are not an official part of this document and are not intended to modify or supercede it.

NOTICE: Conformance to the "should" provisions of this guideline is necessary to declare conformance to this document. Conformance to "may," "suggested," "preferred," "recommended," "NOTE," or "Related Information" provisions is not necessary to declare conformance.

NOTICE: This document contains material that has been balloted and approved by the SEMI Environmental Health and Safety Committee, but is not immediately effective. This material and the date on which it becomes effective are included in Delayed Revisions Sections 1, 2 and 3. The provisions of this information are not an authoritative part of the document until their effective dates. The main body of SEMI S22-0706 remains the authoritative version. Some or all of the provisions of revisions not yet in effect may optionally be applied prior to the effective date, providing they do not conflict with portions of the authoritative version other than those that are to be revised or replaced as part of the deferred change, and are labeled accordingly. Material that is to be replaced by revisions that are not yet in effect is preceded by a NOTICE indicating its status.

1 Purpose

1.1 This guideline provides a set of design based electrical safety considerations for production equipment used in the semiconductor industry.

1.2 Basic product safety concerns can be addressed by satisfying the design, construction, and testing principles set forth in this document or by satisfying the requirements of applicable electrical safety standards.

2 Scope

2.1 This safety guideline applies to semiconductor manufacturing equipment.

2.2 This document contains the following:

1. Purpose
2. Scope
3. Limitations
4. Reference Standards
5. Terminology
6. Alternate Methods of Conformity
7. Design Philosophy
8. General Considerations
9. Facilities Electrical Connection
10. Protection Against Electric Shock
11. Protection Against Risk of Electrical Fire
12. Bonding to the Protective Conductor
13. Safety Circuits
14. Interface Control
15. Electrical Enclosures
16. Conductors and Cables
17. Wiring Practices
18. Electric Motors ¼ Horsepower and Larger
19. Accessories and Lighting

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20. Markings
21. Technical Documentation
22. Testing

2.3 Included in this safety guideline are design considerations for electrical safety interlocks that protect against electrical as well as non-electrical safety hazards; and non-electrical interlocks that protect against electrical safety hazards.

2.4 This document applies to the electrical design for all equipment used to manufacture, measure, assemble, and test semiconductor products unless the equipment is specifically excluded. See § 3, Limitations.

NOTE 1: This safety guideline is most useful for semiconductor manufacturing equipment where no relevant product safety standard exists.

2.5 This safety guideline applies to equipment intended to be powered by hazardous voltages or hazardous electrical power.

NOTE 2: The official values in this guideline are expressed in the International System of Units (SI). Values that:

a) are expressed in Inch-Pound (also known as "US Customary" or "English") units,
b) are enclosed in parentheses, and
c) directly follow values expressed in SI units

are not official, are provided for reference only, and might not be exact conversions of the SI values.

NOTICE: This safety guideline does not purport to address all of the safety issues associated with its use. It is the responsibility of the users of this safety guideline to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This safety guideline does not apply to equipment, subassemblies, and components that have been certified by an accredited testing laboratory and used within their certification parameters, or that conform to a relevant international or national product safety standard as defined by the scope of that standard.

NOTE 3: Criteria for jurisdictional acceptance may vary and should be taken into account although it is beyond the scope of this document.

3.2 This safety guideline is not intended to address any requirements pertinent to explosive atmospheres, hazardous locations, and/or hazardous process materials.

3.3 This safety guideline does not apply to support equipment that is an integral part of the facility, such as facility air conditioning, facility fire detection or fire extinguishing systems, or facility power distribution systems, which include motor-generator sets and transformers.

3.4 This safety guideline does not include design specifications for performance or functional characteristics of the equipment.

4 Referenced Standards and Documents

4.1 *SEMI Standards*

SEMI E33 — Specification for Semiconductor Manufacturing Facility Electromagnetic Compatibility

SEMI S1 — Safety Guideline for Equipment Safety Labels

SEMI S2 — Environmental, Health and Safety Guideline for Semiconductor Manufacturing Equipment

SEMI S3 — Safety Guidelines for Heated Chemical Baths

SEMI S8 — Safety Guideline for Ergonomics Engineering of Semiconductor Manufacturing Equipment

SEMI S10 — Safety Guideline for Risk Assessment and Risk Evaluation Process

SEMI S13 — Safety Guideline for Operation and Maintenance Manuals Used with Semiconductor Manufacturing Equipment

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SEMI S14 — Safety Guidelines for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment

4.2 *IEC Standards*[1]

IEC 60112 — Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions

IEC 60204-1 — Safety of Machinery - Electrical Equipment of Machines, Part 1: General Requirements

IEC 60417 — Graphical Symbols for Use on Equipment

IEC 60529 — Degrees of Protection Provided by Enclosures

IEC 60707 — Flammability of solid non-metallic materials when exposed to flame sources - List of test methods

IEC 60950 — Safety of Information Technology Equipment

IEC 61010-1 — Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use — Part 1: General Requirements

IEC 61346-1 — Industrial systems, installations and equipment and industrial products - Structuring principles and reference designations

4.3 *European Documents*[2]

4.3.1 *CENELEC Standards*

EN 60529 — Degrees of Protection Provided by Enclosures

EN 61508 — Functional Safety of Electrical/electronic/programmable Electronic Safety-related Systems

4.3.2 *European Commission Directives*

89/336/EEC — Directive on Electromagnetic Compatibility

4.4 *NFPA Standards*[3]

NFPA 70 — National Electrical Code

NFPA 79 — Electrical Standard for Industrial Machinery

4.5 *UL Standards*[4]

UL 508A — Industrial Control Panel

UL 94 — Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

UL 943 — Standard for Ground-Fault Circuit- Interrupters

UL 2360 — Standard for Test Methods for Determining the Combustibility Characteristics of Plastics Used in Semi-Conductor Tool Construction

4.6 *ANSI Standards*[5]

ANSI/FM 4910 — Cleanroom Materials Flammability Test Protocol

ANSI/IPC 2221 — Generic Standard on Printed Board Design

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1 International Electrotechnical Commission, 3 rue de Varembé, Case Postale 131, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.919.02.11; Fax: 41.22.919.03.00; http://www.iec.ch

2 European Union ; http://europa.eu.int/

3 National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269, USA. Telephone: 617.770.3000; Fax: 617.770.0700; http://www.nfpa.org

4 Underwriters Laboratory, 333 Pfingsten Rd, Northbrook, IL 60062, USA. Telephone: 877.854.3577; Fax: 847.407.1395; http://www.ul.com

5 American National Standards Institute, Headquarters: 1819 L Street, NW, Washington, DC 20036, USA. Telephone: 202.293.8020; Fax: 202.293.9287. New York Office: 11 West 42nd Street, New York, NY 10036, USA. Telephone: 212.642.4900; Fax: 212.398.0023; http://www.ansi.org

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ANSI/ISA S84.01 — Application of Safety Instrumented Systems for the Process Industries

4.7 *ISO Standards*[6]

ISO 13849-1 — Safety of Machinery – Safety-related Parts of Control Systems – Part 1: General Principles For Design

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 *Definitions*

5.1.1 *access* — a means of approaching or touching.

5.1.2 *accessible* — having or allowing access, see definition of access.

5.1.3 *accredited testing laboratory* — an independent organization dedicated to the testing of components, devices, or systems; competent to perform evaluations based on established safety standards; and recognized by a government or regulatory body.

5.1.4 *ampacity* — the current, in amperes, that a conductor can carry continuously under the conditions of use, without exceeding the design limits for the temperature rating of the insulation, the conductor and the wire termination.

5.1.5 *basic insulation* — provides a single layer of protection against electric shock.

5.1.6 *bonding (bonded)* — the permanent joining of metallic parts to form an electrically conductive path that ensures electrical continuity and the capacity to conduct safely any current likely to be imposed. See *protective earthing system.*

5.1.7 *captive hardware* — screw or nut that is intended to fasten and release other hardware (e.g., a flanged spade lug) by being loosened, but without being removed.

5.1.8 *clearance distance* — the shortest path between two conductive parts normally carrying current, or between a conductive part normally carrying current and a conductive part that is connected to the protective earthing system, measured through air.

5.1.9 *Comparative Tracking Index (CTI)* — the value obtained in accordance with Method A of IEC 60112 which determines the Material Group of a printed wiring board. Where the CTI or material group is not known, Material Group IIIb should be used.

5.1.10 *conduit* — a part of a closed wiring system of circular or non-circular cross-section for insulated conductors and/or cables in electrical installations, allowing them to be drawn in and/or replaced.

5.1.11 *control device (of a machine)* — a device connected into the control circuit and used for controlling the operation of the machine (e.g., position sensor, manual control switch, relay, magnetically operated valve, etc.).

5.1.12 *convenience receptacle* — an electrical outlet provided on the equipment, which does not have any load connected to it during the normal operation of the equipment, but is intended by the equipment manufacturer to be used to power a piece of maintenance or service equipment.

5.1.13 *cord connected equipment* — equipment that is intended to be electrically connected to an electric supply by means of a flexible supply cord and attachment plug.

5.1.14 *creepage distance* — the shortest path between two conductive parts normally carrying current or between a conductive part normally carrying current and a conductive part that is bonded to the protective earthing system, measured along the surface of the insulation.

5.1.15 *disconnecting means* — a device, or group of devices, or other means by which the conductors of a circuit are intended to be disconnected from their source of supply.

5.1.16 *door* — a hinged enclosure panel.

6 International Organization for Standardization, ISO Central Secretariat, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland. Telephone: 41.22.749.01.11; Fax: 41.22.733.34.30, Website: http://www.iso.ch

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5.1.17 *double insulation* — comprised of both supplementary insulation and basic insulation combined.

5.1.18 *duct* — an enclosed channel designed expressly for holding and protecting electrical conductors, cables, and bus bars. Conduits, wireways and under-floor channels are types of ducts.

5.1.19 *earthing* — see *protective earthing system*.

5.1.20 *electrical enclosure* — a panel, compartment, or other defined area housing electrical components used to enhance the safety of the equipment containing those components.

5.1.21 *electrical feed* — (referenced from the equipment) a facility supply conductor that provides electrical energy to a piece of equipment.

NOTE 4: Electrical wiring from enclosure to enclosure, routed through the facility, but provided with the equipment to power subsystems, are not considered electrical feeds.

5.1.22 *energized* — electrically connected to a source of voltage.

5.1.23 *equipment* — a specific piece of machinery, apparatus, process module, or device used to execute an operation. The term "equipment" does not apply to any product (e.g., substrates, semiconductors).

5.1.24 *exposed (as applied to energized parts)* — capable of being inadvertently touched or approached nearer than a safe distance by a person. It is applied to parts that are not suitably guarded, isolated, or insulated.

5.1.25 *fail-safe* — designed so that a failure does not result in an increased risk.

NOTE 5: For example, a fail-safe temperature limiting device would indicate an out-of-control temperature if it were to fail. This might interrupt a process, but would be preferable to the device indicating that the temperature is within the control limits, regardless of the actual temperature, in case of a failure.

5.1.26 *Fail-to-safe equipment control system (FECS)* — a safety-related programmable system of control circuits designed and implemented for safety functions in accordance with recognized standards such as ISO 13849-1 (EN 954-1) or IEC 61508, ANSI SP 84. These systems (e.g., safety Programmable Logic Controller (PLC), safety-related Input and output (I/O) modules) diagnose internal and external faults and react upon detected faults in a controlled manner in order to bring the equipment to a safe state.

NOTE 6: A FECS is a subsystem to a (PES) Programmable Electronic System as defined in IEC 61508 –4.

5.1.27 failure — the termination of the ability to perform an intended function. Failure is an event, as distinguished from "fault," which is a state.

5.1.28 *fault* — the state of an item characterized by the inability to perform its intended function; excludes the inability to perform required functions during preventive maintenance or other planned actions, or due to lack of external resources.

5.1.29 *fault-tolerant* — designed so that a reasonably foreseeable single point failure does not result in an unsafe condition.

5.1.30 *ground fault* — an unintentional, electrically conducting connection between an ungrounded or grounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, or metallic equipment.

5.1.31 *Ground-Fault-Circuit-Interrupter (GFCI)* — a device intended for the protection of personnel that functions to de-energize a circuit or portion thereof within an established period of time when a current to ground exceeds a value in the range of 4–6 mA (for further information, see UL 943, Standard for Ground-Fault Circuit-Interrupters).

5.1.32 *grounding* — see *protective earthing system.*

5.1.33 *hazard* — a condition that is a prerequisite to a mishap.

5.1.34 *hazardous voltage* — voltages greater than 30 Volts RMS, 42.4 Volts peak, or 60 Volts DC.

5.1.35 *hazardous electrical power* — power levels equal to or greater than 240VA.

5.1.36 *insulation* — a layer of non-conductive material used as the outer surface of a conductor for the purpose of protecting against electric shock.

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5.1.37 *interlock* — a mechanical, electrical or other type of device or system, whose purpose is to prevent or interrupt the operation of equipment subsystems under specified conditions.

5.1.38 *interrupting capacity* — the highest current at rated voltage that a device is intended to interrupt.

NOTE 7: Also known as amperes interrupting capacity (AIC).

5.1.39 *isolated power system* — a power system that has a high impedance between its conductors and the facilities connection of the equipment. High impedance can be characterized by resistances of one meg-ohm or more. Isolated power systems are supplied power by isolation transformers or power supplies that have no direct electrical connection between their primary conductors and their secondary conductors.

NOTE 8: An isolation transformer with one leg of the secondary connected to ground is not an isolated power system.

5.1.40 *main disconnecting means* — a disconnecting means that is intended to be used to disconnect facilities electrical power from the system.

5.1.41 *maintenance* — planned activities intended to keep equipment in proper working order (see also the definition for service).

5.1.42 *material group* — a categorization of the Comparative Tracking Index (CTI) of an insulator as follows:

- Material Group I: 600 <= CTI
- Material Group II: 400 <= CTI <600
- Material Group IIIa: 175 <= CTI <400
- Material Group IIIb: 100 <= CTI <175

5.1.43 *maximum nominal load* — the maximum continuous power a circuit will draw under operating conditions prescribed by the manufacturer. Non-periodic power variations of less than a second in duration are not considered continuous.

5.1.44 *multi-outlet assemblies* — assemblies whose primary function is to provide electrical connections and that have multiple receptacles which are intended for electrical connections.

5.1.45 *neutral conductor* — an earthed (grounded) AC current carrying conductor.

NOTE 9: It is distinct from protective earthing which is an earthed (grounded) non-current carrying conductor or a non-earthed (non-grounded) current carrying conductor.

5.1.46 *normal operating conditions* — the condition of the equipment reasonably foreseen by the manufacturer, including specified conditions of use, during operation, maintenance and servicing while the equipment is operated, maintained and serviced according to the manufacturer's instructions and with no unauthorized equipment modifications. Normal operating conditions should include consideration of reasonably foreseeable misuse.

5.1.47 *operator* — a person who interacts with the equipment only to the degree necessary for the equipment to perform its intended function.

5.1.48 *operator access* — an area to which, under normal operating conditions, one of the following applies: access may be gained without the use of a tool, the means of access is deliberately provided to the operator, or the operator is instructed to enter regardless of whether or not a tool is needed to gain access (if the operator is so instructed, this area becomes evaluatable as an operator accessible area).

5.1.49 *overcurrent* — any current in excess of the rated current of the equipment or the rated ampacity (current-carrying capacity) of the conductor; it may result from overload, short circuit, or ground fault.

5.1.50 *overload* — operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload (see *short circuit* and *ground fault*).

5.1.51 *permanently connected equipment* — equipment that is electrically connected to a supply by means of a connection that may be detached only by the use of a tool.

5.1.52 *pollution* — any addition of foreign matter, solid, liquid or gas, that may produce a reduction of dielectric strength or increase of surface resistivity.

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5.1.53 *pollution degree* — for the purpose of evaluating clearances the following two degrees of pollution in the micro-environment are recognized for use with this document:

5.1.53.1 *pollution degree 1* — no pollution or only dry, non-conductive pollution occurs. The pollution has no influence. Cleanroom Class 1000 or less.

NOTE 10: Cleanroom Class 1000 or less is pollution degree 1, however the pollution degree in a particular area in a given piece of equipment may exceed pollution degree 1, even if the equipment is installed in a cleanroom class 1000 or less.

5.1.53.2 *pollution degree 2* — normally only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation is expected. Cleanroom Class greater than 1000.

NOTE 11: Cleanroom Class greater than 1000 is pollution degree 2, however the pollution degree in a particular area in a given piece of equipment may exceed pollution degree 2, even if the equipment is installed in a cleanroom greater than 1000.

5.1.54 *protective conductor* — a conductor that provides electrical continuity between conductive components that are not intended to be energized during normal operations and the equipment's protective earthing conductor terminal.

5.1.55 *protective earthing conductor* — a normally non-current carrying conductor connected between earth (ground) at the source of supply and the protective earthing (grounding) terminal on the equipment enclosure.

5.1.56 *protective earthing conductor terminal* — a terminal bonded to conductive parts of an equipment enclosure for safety purposes and intended to be connected to an external protective earthing (grounding) conductor (the protective earthing conductor).

5.1.57 *protective earthing system* — the earthing (grounding & bonding) system connecting accessible conductive parts of the equipment to an external earth (ground) at the source of supply. The protective earthing system may include bonded structural members, bonding jumpers, the protective earthing conductor terminal on the equipment and the protective earthing conductor in the incoming supply wiring to the equipment.

5.1.58 *raceway* — an enclosed channel of metal, or nonmetallic materials, designed expressly for holding wires, cables, or busbars.

5.1.59 *readily accessible* — capable of being reached quickly for operation or inspection, without requiring climbing over or removing obstacles or using portable ladders, chairs, etc.

5.1.60 *reinforced insulation* — a single layer of insulation that provides a degree of protection against electric shock equivalent to double insulation.

5.1.61 *risk* — the expected losses from a mishap, expressed in terms of severity and likelihood.

5.1.62 *safe shutdown condition* — a condition in which all hazardous energy sources and hazardous production materials are removed or suitably contained, unless this results in additional hazardous conditions.

5.1.63 *safety circuit* — a circuit whose intended function is to make the equipment safer. Interlocks, EMO circuits, and other protective circuits are safety circuits.

5.1.64 *service* — unplanned activities intended to return equipment that has failed to proper working order. See also *maintenance*.

5.1.65 *severity* — the extent of the worst credible loss (damage, injury, or release) from a mishap caused by a specific hazard.

5.1.66 *short circuit current rating* — the maximum prospective available current to which an equipment supply circuit is intended, by the equipment manufacturer, to be connected.

NOTICE: NOTE 12 will be changed upon the July 1, 2009 publication, as shown in Delayed Revisions 2. The Environmental Health and Safety Committee has voted that use of the replacement text is optional before the effective Date.

NOTE 12: Short circuit current rating for an electrical system is typically based on the analysis of short circuit current ratings of the components within the system. See UL 508A for a method of determining short circuit current rating.

5.1.67 *supplementary insulation* — applied to basic insulation in order to ensure protection against electric shock in the event of the failure of basic insulation.

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5.1.68 *testing* — measurements or observations used to validate and document conformance to designated criteria.

5.1.69 *tool* — an external device used to aid a person to perform a mechanical function.

5.1.70 *types of electrical work* — defined by the electrical energy levels a person is exposed to when performing a task. All tasks that should be performed on a system fall into one of the four following type categories of electrical work:

5.1.70.1 *type 1* — equipment is fully de-energized.

5.1.70.2 *type 2* — equipment is energized. Energized circuits are covered or insulated with no exposed parts.

NOTE 13: Type 2 work includes those tasks where the energized circuits are, or may be, measured by placing probes through suitable openings in the covers or insulators.

5.1.70.3 *type 3* — equipment is energized. Energized circuits are exposed and inadvertent contact with un-insulated energized parts is possible. Potential exposures are not greater than 30 Volts rms, 42.4 Volts peak, 60 Volts DC, and 240 volt-amps in dry locations.

5.1.70.4 *type 4* — equipment is energized. Energized circuits are exposed and inadvertent contact with un-insulated energized parts is possible. Potential exposures are greater than 30 Volts rms, 42.4 Volts peak, 60 Volts DC, 240 volt-amps in dry locations, or where induced or contact radio-frequency currents exceed the limits in SEMI S2.

5.1.71 *wire guide* — any method of mechanically securing wire or cable into a restrictive routing.

6 Alternate Methods of Conformity

6.1 The criteria in this document are based on harmonized basic electrical safety considerations. It is not the intent of this document to be the only means of demonstrating the electrical safety conformance of semiconductor manufacturing equipment.

6.2 Equipment that satisfies other national or international electrical product safety standards meets the intent of this document.

7 Design Philosophy

NOTE 14: This section is intended to provide general design guidance to engineers; for specific design considerations see §§ 8–22.

7.1 This document should be used during the electrical design, construction, and evaluation phases of semiconductor manufacturing equipment. The intent of this safety guideline is to provide a design based electrical document that will be useful to both design engineers and evaluators, in order to facilitate electrical safety in the equipment.

7.2 Designers that understand these general principles of safety are more likely to design safe equipment. This section is not an alternative to the more specific engineering considerations of this safety guideline, but is intended to provide designers with an appreciation of the basic safety principles.

7.3 Electric shock is due to current passing through the human body. Currents on the order of a milliampere may cause a reaction in people in good health, and may cause indirect mishap due to involuntary reactions. Higher currents may have higher severity risks.

7.4 Design of equipment should provided protection of personnel from electric shock or arc flash/blast that may result from reasonably forseeable single faults.

7.5 Service and maintenance personnel should be protected against inadvertent contact with electrical hazards.

7.6 Movable cord-connected equipment is considered to present a slightly increased risk of shock as well as overheating, due to strain on the supply cord leading to damage to the connections, insulation, and the protective earthing conductor. With portable cord-connected equipment, wear on the cord is more likely, and further hazards could arise if the equipment were dropped.

7.7 Short-circuiting between phases and phase to ground of high current supplies or high capacitance circuits may cause arcing or ejection of molten metal which may cause burns. Even low voltage circuits may be dangerous in this respect. Protection should be provided by adequate separation, by shielding, or by using safety interlocks.

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7.8 When temperatures that could cause a hazard result from overloads, component failure, insulation breakdown, high resistance or loose connections, the risk of fire may be reduced by one or more of the following means:

a) taking all reasonable steps to avoid high temperatures which might cause ignition;
b) controlling the position of combustible materials in relation to possible ignition sources;
c) limiting the quantity of combustible materials used;
d) using barriers, if necessary, to limit the spread of fire within the equipment beyond the immediate vicinity of the ignition source; and/or
e) using suitable materials for the outer fire enclosures of the equipment.

NOTE 15: SEMI S14 may also be used for guidance on fire risk mitigation.

NOTE 16: Some fire retardant components or materials may be restricted or banned in certain jurisdictions.

7.9 Equipment should be designed to prevent injury due to excessive (high or low) temperatures of parts; to ensure that the equipment is mechanically stable and structurally sound; to avoid the presence of operator accessible sharp edges and points; and to provide adequate guarding or safety interlocking of hazardous moving parts.

7.10 Materials used in the construction of equipment should be selected and arranged so that they may be expected to perform in a reliable manner, without a risk of energy hazard or electric shock developing, and such that they would not contribute significantly to the development of a significant fire hazard.

NOTE 17: Some electrical components such as relays, electrolytic capacitors, batteries, solder, cathode ray tubes, finished chassis, fluorescent lights and connectors may contain materials that are restricted or banned in certain jurisdictions.

8 General Considerations

8.1 The risks associated with the electrical design, construction, and operation of the equipment should be considered as part of the overall safety assessment of the equipment. This assessment should include a fault analysis with consideration given to, but not limited to, electric shock or fire and failures of components, subsystems, and systems.

8.2 The following are some of the types of faults that should be considered:

a) faults and failures in the equipment's circuits, and
b) possible human error associated with operator, maintenance, and service activities.

NOTE 18: This is not intended to be a comprehensive list of all possible types of faults.

8.3 The order of precedence for resolving identified hazards and satisfying equipment safety considerations should be as follows:

a) design to eliminate hazards,
b) incorporate safety devices,
c) provide hazard alerts or warning signals, and finally
d) develop administrative procedures and training (administrative procedures may include the use of personal protective equipment).

8.3.1 A combination of these approaches can also be used.

NOTE 19: See SEMI S2 for additional information.

8.4 *Electrical Components*

8.4.1 Where failure of components and assemblies could result in an unacceptable increase in risk of electric shock, fire, or personnel injury, those components and assemblies should be certified by an accredited testing laboratory and used in accordance with the manufacturer's specifications and conditions of the certification, or otherwise evaluated to the relevant component standard(s). This applies to components that handle hazardous voltage or hazardous electrical power or are used in a safety circuit.

NOTE 20: Reference SEMI S2 for discussions of acceptable risk.

8.4.2 Components should be provided with overcurrent protection in accordance with § 11.

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8.4.3 Components should be securely mounted according to the conditions of their certification, if applicable, and their manufacturer's instructions.

8.5 *Electrical Supply*

8.5.1 The equipment should be designed to operate safely when connected to its specified electrical supply.

8.5.2 Interruptions in the facilities electrical supply should not lead to an increased risk of fire, electric shock, or other hazardous conditions.

8.6 *Un-interruptible Power Supplies (UPS)* — This subsection applies to UPSs with outputs greater than 30 Volts rms, 42.4 Volts peak, 60 Volts DC or 240 Volt-Amperes (VA). Whenever a UPS is provided with the equipment, its location and wiring should be clearly described within the relevant manufacturer supplied documentation that covers installation and maintenance.

8.6.1 Power from the UPS should be interrupted when any of the following events occur:

a) the emergency off actuator (EMO button) is pushed; or
b) the equipment main disconnecting means is opened.

EXCEPTION: Upon emergency off (EMO) activation, the UPS may continue to supply power to the EMO circuit, safety related devices, and data/alarm logging computer systems as described in the exception clauses of ¶ 13.3.3.

8.6.2 The UPS may be physically located within the footprint of the equipment provided that the UPS is within its own electrical enclosure, which may be the enclosure provided with the UPS and considered in the certification of the UPS. The UPS circuits may also be supplied from a facility source outside of the equipment served. If this is the case, then all the considerations discussed for facilities main disconnecting means in § 9 should be taken into account for power supplied to the UPS circuits.

8.6.3 The UPS should be certified by an accredited testing laboratory.

8.6.4 The UPS wiring and terminals should be identified as "UPS Supply Output," or equivalent, at each connection point where the UPS wiring may be disconnected.

8.7 *Operating Environment* — The electrical equipment should be suitable for the environment in which it is intended to be used.

8.8 *Electromagnetic Compatibility (EMC)* — A system malfunction, as a result of the presence of anticipated electromagnetic disturbances that will be present in the end use environment, should not result in an unacceptable risk. Products that are compliant with either SEMI E33 or the EMC Directive (89/336/EEC) are considered to be compliant with this criterion.

8.9 *Contaminants*

8.9.1 Electrical equipment should be adequately protected against the entrance of solid bodies and liquids likely to be present that may increase the risk of electric shock or fire as a result of a single-point failure or reasonably foreseeable operational error.

8.9.2 Electrical insulation should be protected against chemical environments that may lead to deterioration, or be capable of withstanding the environments to which it will be exposed.

8.10 *Ionizing and Non-ionizing Radiation* — Personnel should be adequately protected against the hazards associated with ionizing and non-ionizing radiation. Compliance to the ionizing and non-ionizing radiation sections of SEMI S2 serves as verification of compliance.

8.11 *Vibration, Shock, and Bump* — Protection should be provided against likely unsafe consequences from the effects of vibrations, shocks and bumps caused by operation of the equipment, or disturbances of this type that will be present in the semiconductor manufacturing, testing, and assembly environment.

NOTE 21: See the SEMI S2, Seismic section, for considerations.

8.12 *Transportation and Storage* — Packing for shipment should prevent damage from humidity, vibration, and shock that may affect the safety of the equipment.

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EXCEPTION: Installation considerations for checking safety related aspects of the system that may be impacted during transportation and storage may be used instead of the packing stipulations of ¶ 8.12.

8.13 *Provisions for Handling* — Provisions for lifting and handling sub-systems that may cause injury when moved or lifted during maintenance or service should be provided and documented in the system manuals. See SEMI S8 for further information.

8.14 *Lockout (electrical energy isolation)* — Lockable energy isolation devices should be designed into equipment to provide for safety during service and maintenance tasks. Where it is expected that it will be necessary or beneficial to work on separately operable parts of the equipment, a separate lockable energy isolation device may be provided for each such part.

8.15 *Suspension of Safeguards* — General energy isolation, local energy isolation, or safe work procedures should be used when there is a suspension of safeguards. These procedures should be defined in the maintenance manual.

9 Facilities Electrical Connection

9.1 *Incoming Supply Conductors*

9.1.1 Equipment should be designed to receive incoming electrical power from the facility to a single feed location which terminates on the specified main disconnecting means. This main disconnecting means, when opened, should remove all electrical power in the equipment from the load-side of the main disconnecting means.

EXCEPTION 1: Equipment with more than one electrical feed should be provided with provisions for energy isolation ("lockout") for each feed and be marked with the following text, or the equivalent, at each main disconnecting means: "WARNING: Risk of Electric Shock or Burn. Disconnect all [number of feed locations] sources of supply prior to servicing."

EXCEPTION 2: Multiple units mounted separately with no shared hazards and without interconnecting circuits with hazardous voltages, energy levels, or other potentially hazardous conditions may have: separate sources of power and separate supply circuit main disconnecting means; or separate EMO circuits, where all of the above are clearly identified.

NOTE 22: If general lockout cannot be performed for a specific maintenance or service task the guidance in § 8.15 should be followed.

9.1.2 Field installed supply conductors should be connected directly to the main disconnecting means with no connection to terminal blocks or other devices.

EXCEPTION: This does not apply where the plug of a cord is the main disconnecting means. However, if the plug of the cord is not the main disconnecting means then field installed supply conductors should be connected directly to the main disconnecting means with no connection to terminal blocks or other devices.

9.1.3 Terminals with hazardous potentials present after the main disconnecting means is placed in the "Off" isolation position should be identified with an appropriate hazard warning label. The label should be placed inside the electrical enclosure adjacent to the terminals.

9.1.4 The supply overcurrent protection should be rated adequately to protect components connected to the supply circuit that do not otherwise have adequate overcurrent protection.

9.1.5 The equipment should be provided with main overcurrent protection devices rated with an interrupting capacity of at least 10,000 rms symmetrical amperes interrupting capacity (AIC) for circuits rated 240VAC or less, and at least 14,000 rms symmetrical amperes interrupting capacity (AIC) for circuits rated more than 240VAC.

EXCEPTION 1: Cord connected single phase equipment, rated no greater than 2.4 kVA, may have overcurrent protection devices with an interrupting capacity of at least 5,000 rms symmetrical amperes interrupting capacity. When this exception is used the installation manual should inform the user of the lower AIC protection provided by the equipment.

EXCEPTION 2: An equipment subsystem (e.g., minienvironment ventilation) rated no greater than 2.4 kVA, may have overcurrent protection devices with interrupting rating of at least 5,000 rms symmetrical amperes interrupting capacity (AIC).

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9.1.6 *Identification of Facilities Connections*

9.1.6.1 Where a neutral conductor is used it should be clearly indicated in the equipment schematic drawings and the facilities supply connection should be labeled "N" or "Neutral."

EXCEPTION: This marking is not necessary in cord connected equipment where the cord is not installed in the field.

9.1.6.2 At each incoming supply point, the protective earthing conductor terminal should be identified by the earthing symbol (see IEC 60417 symbol 5019). In addition to the earthing symbol, other appropriate letter designations may be applied (e.g., "PE," "GND").

9.1.6.3 Installation instructions should be provided for the correct identification and installation of the individual phases in a three phase system when the improper connection of phases could result in hazardous unintended rotation or sequence.

9.1.6.4 Each unearthed phase conductor in 3 phase AC power circuits should be clearly indicated in the equipment schematic drawings, and the facilities incoming supply connection should be identified with one of the following schemes adjacent to the input terminals:

a) "L1," "L2," and "L3,"
b) "R," "S," and "T," or
c) "A," "B," and "C."

9.2 *Equipment Protective Earthing Connection*

9.2.1 A protective earthing conductor should enter the equipment in association with the incoming supply conductors.

9.2.2 The protective earthing conductor should be copper.

9.2.3 The protective earthing conductor should be sized in accordance with the tables in Appendix 1. See Appendix 1, Tables A1-1–A1-5 for protective earthing conductor sizes.

9.2.4 The protective earthing conductor terminal should be dedicated for the sole purpose of connecting the protective earthing conductor to the equipment protective conductors and bonding system.

9.2.5 The protective earthing conductor and its connection to the protective earthing conductor terminal should also comply with the protective bonding section of this safety guideline (see § 12).

9.2.6 The protective earthing conductor should not be used as an intentional current carrying conductor for the power delivery circuit. Currents on the protective earthing conductor from EMC filters are permissible. The protective earthing conductor may also carry currents that result from incidental inductive and capacitive coupling.

9.2.7 There should be no connection between the supply neutral conductor and the protective earthing conductor or the protective earthing system inside the electrical equipment.

9.3 *Main Disconnecting Means*

9.3.1 The main energy isolation capabilities (equipment main disconnecting means) should be in a location that is readily accessible and should be lockable only in the de-energized position.

9.3.2 For equipment with multiple incoming electrical feeds, all of the main disconnecting means should be grouped in one area or a marking should be installed at each supply circuit main disconnecting means location indicating the number of all other supply circuit main disconnecting means.

NOTE 23: Grouping main disconnecting means in one area is preferred.

9.3.3 Supply conductor connections to the main disconnecting means should comply with one of the following:

a) the connections should be located in a separate electrical enclosure installed on or adjacent to the equipment enclosing the main disconnecting means only. Parts on the supply side of the main disconnecting means in the equipment which remain energized when the main disconnecting means is switched off should be guarded (finger-safe) to prevent accidental contact by service personnel; or
b) the connections should be located within the main electrical enclosure located near the top, with adequate bending space provided for supply conductor installation and no equipment located above the supply terminals.

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Parts on the supply side of the main disconnecting means in the equipment which remain energized when the main disconnecting means is switched off should be guarded (finger safe) to prevent accidental contact by service personnel; or

c) the connections should be located within the main electrical enclosure, where other equipment is mounted above the supply terminals. Parts on the supply side of the main disconnecting means in the equipment which remain energized when the main disconnecting means is switched off should be guarded to prevent accidental contact by service personnel or by a tool that may be dropped from above. The opening should be such that a 1 mm (0.04 inch) rod cannot come into contact with the energized parts.

EXCEPTION: Machines with a power consumption totaling 1492 Watts (2 HP) or less may be connected to a remotely mounted main disconnecting means through a flexible cord, cable, or conduit provided that the main disconnecting means is in sight from, readily accessible to, and no more than 6 m (20 feet) from the machine operator work station.

9.3.4 Wire bending space should be provided for the facility supply conductors at the main disconnecting means as specified by Appendix 1, Tables A1-1–A1-5.

EXCEPTION: Equipment that meets the wire bending space requirements of NFPA 70 will also meet these criteria.

9.3.5 When placed in the off position the main disconnecting means should satisfy the following criteria:

a) All unearthed conductors of the supply circuit should be disconnected simultaneously.

b) Earthed conductors (neutral or grounded) should not be disconnected.

EXCEPTION: The earthed conductor (neutral) may be disconnected provided that it is disconnected simultaneously with the unearthed conductors.

NOTE 24: Some jurisdictions require disconnection of the earthed conductor (neutral).

9.3.6 The main disconnecting means should have a minimum of two marked positions, “Off” (isolated) and “On.” These positions should be clearly marked with IEC 60417 symbol 5008 for “Off” and IEC 60417 symbol 5007 for “On.”

9.3.7 The actuator of the equipment’s main disconnecting means should be readily accessible and a maximum of 2 meters above the standing surface, measured from the center of the grip.

9.3.8 Each facility main disconnecting means for the incoming electrical supply should be mechanically or electrically interlocked, or both, with the electrical disconnect enclosure door.

EXCEPTION 1: A main disconnecting means used only for maintenance of lighting circuits within electrical enclosures should not be interlocked with the electrical enclosure door. A hazard warning label should be provided when exposed parts may be energized within the main disconnect enclosure when the enclosure door is open.

EXCEPTION 2: Where an attachment plug is used as the main disconnecting means.

EXCEPTION 3: Where a remotely mounted main disconnecting means is provided, a tool is required to open the equipment enclosure door, and a hazard warning label is attached to the electrical enclosure warning of hazardous voltage inside and advising isolation of the power before opening.

EXCEPTION 4: The considerations stated in ¶ 9.3.8 do not apply to equipment rated less than 5KVA that has the other protections against electric shock stipulated in this document.

9.3.9 The main disconnecting means (lock-out) handle should not disengage from the main disconnecting means when the enclosure door is opened.

9.3.10 Interlocking should be provided between the main disconnecting means and its associated door to prevent both of the following:

a) closing of the main disconnecting means while the enclosure door is open, unless the interlock disconnecting power is overridden by a deliberate action (see § 13), and

b) closing of the main disconnecting means until the door hardware is fully closed.

NOTE 25: A mechanical interlock is preferable to an electrical interlock.

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9.4 *Cord and Plug Connections Used as Facility Connection*

9.4.1 When a cord and plug connection is intended to be used as a main disconnecting means, it should either be capable of being under the exclusive supervision of the person carrying out the work, or be provided with a means for lockout. See discussion of conductors and cables in § 16.

9.4.2 If a supply cord is provided with the system, the cord, as well as the installation instructions, should comply with applicable local codes where it will be installed, or the equipment should have provisions for hard wiring using a raceway.

9.4.3 If there are provisions for hard wiring, a cord and plug should not be used as a main disconnecting means.

9.4.4 If the cord and plug is used for the main disconnecting means the equipment should also have an on-off control.

NOTE 26: Uses preferred for cord and plug connection to the facility include:

a) equipment with an attachment plug and powered from a receptacle outlet to connect movable equipment to facilitate frequent interchange, and
b) the fastening means and mechanical connections of the equipment are designed to permit removal for maintenance or service.

NOTE 27: Materials are restricted by ¶ 16.3.1.

10 Protection Against Electric Shock

10.1 *General* — The electrical equipment should provide protection to persons against electric shock under normal operating conditions and under any reasonably foreseeable single fault condition.

10.2 *Protection Against Electric Shock During Normal Operation*

10.2.1 Where operator access to a hazardous voltage is controlled through the use of a grounded conductive or non-conductive enclosure, that enclosure should either:

1) require a tool to open and be labeled with the hazard against which it protects personnel, or
2) be interlocked.

10.2.1.1 Reference Jointed Finger Probe Access Test. Reference IEC61010-1 Annex B for the test finger.

NOTE 28: IEC 60529 "Degrees of Protection Provided by Enclosures" may be used as a reference.

10.2.2 Spacing between uninsulated energized parts and conductive enclosures should be maintained in compliance with Appendix 1 Tables A1-12 and A1-13 or determined to be adequate by dielectric testing in accordance with § 22.

10.2.3 Energized parts protected by insulation should be completely covered with insulation that can be removed only by destruction. Such insulation should be capable of withstanding the mechanical, chemical, electrical, and thermal stresses to which it may be subjected under normal operation.

10.2.4 *Protection Against Electric Shock Hazards Resulting from Fault Conditions* — Use of measures to prevent the occurrence of a hazardous touch voltage may include one or more of the following:

a) Double or reinforced insulation may be used to prevent a hazardous touch voltage through contact with exposed conductive parts that results from the failure of basic insulation of the energized parts of that circuit,
b) Electrical separation (clearance and creepage) may be used to prevent a hazardous touch voltage through contact with exposed conductive parts that results from the failure of basic insulation of the energized parts of that circuit,
c) Automatic disconnection of the supply of any circuit affected by the occurrence of an insulation failure that results in a ground fault may be used to prevent contact with a hazardous voltage.

NOTE 29: See definition of GFCI.

10.3 *Maintenance and Service Personnel Potential Exposure to Hazards*

10.3.1 *Energized Electrical Work* — The equipment should be designed to minimize the need to calibrate, modify, repair, test, adjust, or maintain equipment while it is energized, and to minimize work that should be performed on

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components near exposed hazardous energized circuits. The equipment design should move as many tasks as practical from Type 4 to Types 1, 2, or 3. Routine Type 4 tasks, excluding troubleshooting, should have specific written instructions in the maintenance manuals. General safety procedures (e.g., appropriate PPE and barriers) for troubleshooting, including Type 4 work, should be provided in the maintenance manual.

10.3.2 *Protection of Service Personnel* — Service personnel should not be exposed to inadvertent contact with hazardous potentials or hazardous energy levels. This may be accomplished by using touch safe terminals or providing additional barriers over exposed terminals.

10.3.3 *Manual Adjustment* — Equipment requiring manual adjustment should be so designed that adjustment does not expose personnel to electrical or mechanical hazards.

10.3.4 *Access* — Maintenance and service access should be provided for maintaining and servicing equipment.

10.3.5 *Internal Barriers* — Non-conductive or earthed (grounded) conductive physical barriers or equivalent means should be provided:

a) where it is necessary to reach over, under or around, or in close proximity to hazards,
b) where dropped objects could cause short circuits or arcing,
c) where failure of liquid fittings from any part of the equipment could result in the introduction of liquids into electrical parts,
d) where maintenance or service tasks are likely to allow inadvertent contact with un-insulated energized parts containing either: potentials greater than 30 Volts rms, 42.4 Volts peak, or 60 Volts DC; or power greater than 240 volt-amps in dry locations.

NOTE 30: Removable nonconductive and noncombustible covers are preferred.

10.3.6 *Test Points* — When test points are provided they should satisfy the following:

a) located to provide unobstructed access,
b) marked or identified in the documentation,
c) protected against incidental contact, and
d) provide adequate access for a test probe.

10.3.7 *Isolated Power Systems* — This section applies only to 50–60 Hz AC applications operating at a hazardous voltage.

NOTE 31: The common purpose for using isolated power systems is to reduce sources of electronic noise by not deliberately referencing the output circuit conductors to earth (ground).

NOTE 32: Auto transformers do not provide electrical isolation.

10.3.7.1 All accessible conductive components that are likely to become energized under fault conditions should be effectively bonded to the protective earthing conductor.

EXCEPTION: If the process technology requires conductive parts that are not grounded when they are inaccessible, but grounded when they are accessible, then the intent of ¶ 10.3.7.2 is satisfied by ensuring such conductive parts are grounded when they become accessible.

10.3.7.2 Isolated circuits should meet the following:

a) the transformer or power supply, and any components (devices) connected to their output, should be clearly labeled adjacent to the isolated circuit(s) or on the enclosure to warn operators and service personnel of the unearthed condition, and
b) ground detection lights, a ground-fault circuit-interrupter (GFCI), or a line isolation monitor should be installed in the output circuit to indicate an isolated conductor ground-fault condition. This will aid in the detection of ground faults in isolated power systems.

10.3.8 *Protection Against Residual Voltages* — Stored electrical energy should be draine d to less than a hazardous energy level. See § 22 for test method.

EXCEPTION: Batteries that produce a hazardous electrical power or hazardous voltage do not need to be discharged, but other provisions for safe servicing should be made and provided in the system documentation.

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11 Protection Against Risk of Electrical Fire

11.1 Measures should be provided in the design of the equipment to protect against the risk of electrical fire as a result of any reasonably foreseeable single fault due to component failure or abnormal operating conditions.

11.2 The installation documentation should include the necessary data for selecting the facility supply overcurrent protective device and the facility supply conductors.

11.3 All conductors except protective earthing conductors, protective conductors, and earthed (for example, neutral) conductors should be protected against overcurrent conditions by protective devices suitably chosen as discussed in the remainder of this section.

EXCEPTION: The earthed conductor (neutral) may be disconnected by an overcurrent device for valid safety and design reasons, providing that it is disconnected simultaneously with the unearthed conductors.

11.4 Circuit overcurrent protection devices should not exceed the ampacity of the conductors they protect.

NOTICE: The addition of a new ¶ 11.5, renumbering of all of the remaining paragraphs of § 11, and addition of an appendix upon July 1, 2009 publication as shown in Delayed Revisions 1. The Environmental Health and Safety Committee has voted that the use of this material is OPTIONAL before the Effective Date.

11.5 Circuit overcurrent protection of discrete devices should not exceed 125% of the amperage rating of the device. See § 18 for motor protection.

11.6 Circuits that cannot be characterized as serving discrete devices should be provided with overcurrent protection at 125% of maximum nominal load or the next largest standard size of overcurrent device, unless it can be demonstrated that no risk of electrical fire is present in the event of fault conditions (e.g., power limited).

11.7 All receptacle outlets and connectors as well as the circuits supplying these receptacles should have overcurrent protection in accordance with their rating.

11.8 *Local Lighting Circuits* — Overcurrent protection for lighting circuits should not exceed 15 amperes.

11.9 *Transformers*

11.9.1 Transformers that operate at 50/60 Hz, that have a primary rated 600VAC or less, and have no integral thermal protection should have overcurrent protection in accordance with the applicable row of Table A1-14.

11.9.2 Transformers that operate at 50/60 Hz, that have a primary rated 600VAC or less, and are equipped with thermal protection provided by the transformer manufacturer that interrupts the primary current in the event of an overload, should be protected in accordance with Table A1-14 or A1-15.

NOTE 33: Where current ratings are not given by the manufacturer, calculation methods to help determine them are provided in Related Information 1 and 2.

11.10 *Overcurrent Protective Devices*

11.10.1 *Overcurrent Devices* — All overcurrent protective devices should be selected and applied with proper consideration being given to the following:

a) maximum available fault current,
b) interrupting rating of the device,
c) voltage rating,
d) load characteristic,
e) normal operating current, and
f) circuit in-rush characteristics.

11.10.2 Circuit breakers and circuit protectors are preferred over fuses as overcurrent devices because they can be reset.

11.10.3 Fuse holders and fuses should be of a type that is designed to be mounted to a panel or component rail.

NOTE 34: So-called ‘inline’ fuse holders does not meet this criteria.

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11.10.4 Panel-mounted fuse holders and fuses should satisfy the following:

a) fuses in screw-type fuse holders should be used as overcurrent protection in only single-phase circuits using a neutral conductor;

EXCEPTION: Fast-acting fuses in multi-phase circuits may be used where they can enhance safe design.

b) if electric shock due to incidental contact by maintenance or service personnel may occur, a touch-safe fuse holder should be used;

c) fuse holders that have exposed metal when the cap is removed (non-shockproof fuse holders) should have the line conductor connected to the end terminal and the load conductor connected to the side terminal; and

d) fuse holders should not move in a way that will loosen electrical connections when a fuse is replaced.

11.10.5 Circuit breakers and circuit protectors should satisfy the following:

a) The circuit breaker or circuit protector should be manually operable and should clear a fault even if the handle mechanism is held closed;

b) The "ON" and "OFF" position should be clearly marked. The handle should be mounted with the handle up for the "ON" position;

c) If the circuit breaker is mounted on a vertical surface it should be in a vertical or horizontal orientation only. If mounted in a vertical orientation, the handle should be up for the "ON" position. If mounted in a horizontal orientation, the handle should be to the right for the "ON" position. If mounted in two columns, horizontally oriented, the handles should be toward the center for the "ON" position; or clearly marked indicating the "ON" and "OFF" positions.

d) If the circuit breaker is mounted on a horizontal surface it should be mounted so that the on position is to the right of the surface or center if there are two columns; or it should have its "ON" and "OFF" position clearly marked.

e) Overcurrent protection should be provided in all unearthed conductors.

NOTE 35: It is preferred that the supply conductors of the circuit be connected to the top of the circuit breaker or circuit protector where practical. Circuit breakers and circuit protectors marked with "line" and "load" terminals should be installed in accordance with the markings.

11.11 *Electrolytic Capacitors*

11.11.1 Large capacitor venting recommendations: Capacitors that are greater than 25.4 mm (1 inch) in diameter or are capable of storing more than four Joules should be self-vented or protected from rupture by equivalent means. A capacitor vent should be unobstructed for a minimum of 5.1 mm (0.2 inch). Capacitors mounted horizontally should have vent holes positioned in the upper half of the enclosure (9, 12, 3 o'clock positions).

11.11.2 Capacitors should have containment provisions within the capacitor itself or be shielded such that vapors or debris will not become hazardous to personnel.

11.11.3 Capacitor terminals should be insulated or protected from short circuits by tools. Lacquer and sealing compounds should not be relied upon to provide protection.

11.12 *Abnormal Temperatures Under Fault Conditions* — Heaters or other circuits which, under any reasonably foreseeable single fault condition, are capable of causing abnormal temperatures that create a hazardous condition with an unacceptable level of risk, should be provided with over temperature protection to detect these abnormally elevated temperatures and interrupt the source of energy driving them. Equivalent means of protection are acceptable.

11.13 In addition to satisfying the criteria of this document, the criteria of SEMI S3 should be satisfied when applicable.

11.14 Some device loads vary widely depending upon their operating conditions and operating history (such as ceramic resistive heating elements). The load values used to select overcurrent protection devices should account for the full load range during worst case, normal operating conditions.

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12 The Protective Earthing System

12.1 *Bonding* — All accessible non-current carrying conductive components that may become energized under reasonably foreseeable single fault conditions, and as a result increase the risk of electric shock, should be bonded to the protective earthing system.

NOTE 36: Non-safety related bonding conductors (e.g., bonding conductors for EMC concerns) are not subject to this section.

12.2 *Parts Not Bonded to the Protective Earthing System* — If non-current carrying conductive parts do not constitute a hazard under single fault conditions, it is not necessary to bond them to the protective earthing system.

12.3 *Protective Earthing System*

12.3.1 *General* — The protective earthing system consists of those components that provide electrical continuity between the protective earthing conductor terminal and non-current carrying frames, enclosures, or components that are stipulated to be maintained at an earth potential under both normal operating conditions and single fault conditions in accordance with ¶ 12.1.

12.3.2 *Protective Conductors* — Copper conductors or structural members with bonding jumpers should be used for bonding to the protective earthing system.

EXCEPTION: Conductors other than copper that have equivalent ampacity to copper conductor can be used for protective conductors.

12.3.2.1 When a protective conductor is used in this way, its size should be compatible with the protective conductor ampacity given in Tables A1-1–A1-5 that is a function of the ampacity of the current carrying conductor it is associated with.

12.3.2.2 Bus bars, and/or the equipment frame may be used as protective conductors. When bus bars or the equipment frame is used, their geometry and material should provide the same ampacity as that stipulated for the protective conductor in Tables A1-1–A1-5.

12.3.3 Hinges, slides, and other moving parts of enclosures should not be relied on as part of the protective earthing system.

EXCEPTION: Hinges are acceptable if the enclosure and its hinges have been identified as suitable for bonding by an accredited testing laboratory.

12.3.4 Raceways, wireways, and cable trays should not be used as protective conductors, except to effect their own connection to the protective bonding circuit as may be stipulated by ¶ 12.1.

12.3.5 It is preferred that a protective conductor be routed with the associated current carrying conductors whenever possible.

12.3.6 The protective earthing system should not be intentionally used as a current carrying conductor, except as permitted by ¶ 9.2.6.

12.3.7 *Continuity of the Protective Earthing System* — The protective earthing system should be permanent, electrically continuous and capable of carrying any ground fault current likely to be imposed. See ¶ 22.3 "Earthing Continuity and Continuity of the Protective Bonding Circuit" for the appropriate test method.

12.3.8 Connection and bonding points to protective conductors should be designed so that their current carrying capacity is not impaired by mechanical, chemical, or any other influence that may degrade their current carrying capacity.

12.3.9 Mounting hardware and cover screws that may be removed for normal servicing should not be used for terminating the protective conductor to a component or part of the enclosure.

12.3.10 Machine parts, other than accessories or attachments, having metal-to-metal bearing surfaces should be considered as bonded to the protective earthing system. Parts separated by a nonconductive fluid or gas should not be considered as bonded.

12.3.11 When a part is removed, the continuity of the protective earthing system for the remaining parts should not be interrupted.

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12.3.12 *Exclusion of Switching Devices from the Protective Bonding Circuit* — The protective earthing system should not incorporate switching or interruption devices.

EXCEPTION: For technologies requiring isolated potentials (i.e., no ground reference) during operation, ground interrupting devices are acceptable provided the device automatically provides continuity of the protective earthing system when the related components are accessible and that the device is fault tolerant.

12.3.13 *Interruption of the Protective Earthing System* — Where the continuity of the protective earthing system can be interrupted by means of connectors (e.g., plug and socket connections), and this could result in increased risk of electric shock, the following considerations should be satisfied:

a) the protective earthing system should be interrupted only after the energized conductors have been interrupted, and

b) the continuity of the protective earthing system should be re-established before any energized conductor is reconnected.

12.4 *Bonding Terminations to the Protective Earthing System*

12.4.1 The protective conductors should be bonded to a single designated termination (the protective earthing conductor terminal) that will not be disturbed by any other conductor terminations.

12.4.2 All non-conductive coatings, such as paint or enamel, should be removed from contact surfaces where protective conductors terminate.

12.4.3 Terminals for bonding conductors to the protective earthing system should be ring terminal with non-captive hardware or flanged fork with captive hardware. Where routine removal is anticipated, flanged fork with captive hardware is preferred. For bonding with protective circuit, it is preferred that a lock or star washer be included.

12.4.4 Terminal lugs used to make connections to the protective earthing system do not need to be insulated.

12.5 Cord and plug connected equipment should pass a leakage current test in accordance with the test described in § 22.

13 Safety Circuits

13.1 *General* — Transformers or power supplies should be used for supplying safety circuits. Such transformers should have electrical isolation between the primary and the secondary windings. Safety circuits should be designed using non-hazardous voltage and power levels consistent with the correct operation of the control circuit.

NOTE 37: See ¶ 13.3.3 EXCEPTION 2 for specific EMO function exception.

13.2 *Start Functions*

13.2.1 Start functions should operate by energizing the relevant circuit.

13.2.2 *Prevention of Unexpected Start-up* — The engineering design should prevent unexpected start-up.

13.3 *Emergency Off*

13.3.1 The equipment should have an “emergency off” (EMO) circuit. An EMO actuator (e.g., button), when activated, should place the equipment into a safe shutdown condition, without generating any additional hazard to personnel or the facility.

EXCEPTION 1: Cord- and plug-connected single phase equipment, rated no greater than 240 Volts line-to-line/150 Volts line-to-earth and no greater than 2.4 kVA, where the hazards are only electrical in nature, do not need to have a separate EMO circuit if the main disconnecting means is readily accessible to the operator and maintenance personnel. This main disconnecting means should be red and labeled indicating its On/Off status.

EXCEPTION 2: Assemblies that are not intended to be used as stand-alone equipment, but rather within an overall integrated system, and which receive their power from the end-user system, may not have a separate emergency off circuit. The assembly’s installation manual should provide clear instructions to the equipment installer to connect the assembly to the integrated system’s emergency off circuit.

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