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National Aeronautics and Space Administration

SPACE TRANSPORTATION SYSTEM
ORBITER UPGRADES PROGRAM

Electrical Auxiliary Power Unit (EAPU)
Corona Design Guideline

Document No: JSC-29129

Revision 1.0

Date: June 29, 2000

[redacted]

Electrical Auxiliary Power Unit (EAPU) Corona Design Guideline

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1.0 PREFACE

This document is the result of a collaborative effort between NASA's Johnson Space Center, Marshall Space Flight Center, Glenn Research Center, and the United States Air Force Research Laboratory at Wright Patterson AFB in support of the Space Shuttle Orbiter Upgrades Program, specifically the Electric Auxiliary Power Unit Program.

This document is intended as a guideline for design applications for corona and partial discharge avoidance and is not a requirements specification instrument.

2.0 SCOPE

2.1 Purpose

This document describes design guidelines for avoiding damage due to corona, partial discharge, or plasma interactions for the Space Transportation System (STS) Orbiter Spacecraft Electric Auxiliary Power Unit (EAPU) System.

2.2 Applicability.

This document is applicable to the Space Transportation System (STS) Orbiter Spacecraft Electric Auxiliary Power Unit (EAPU) System. It applies to 50 missions for the Electro Hydraulic Drive Unit (EHDU), and 100 missions for the Electric Power Distribution and Control (EPDC).

Potential corona or plasma susceptible designs shall be reviewed for compliance to the guidelines contained herein. Components for which the compliance cannot be verified by demonstration test, analyses, or historical usage equivalency (similarity) should be modified to comply, or be eliminated from the system design.

Adherence to the recommended design and assembly practices contained herein will minimize the probability of non-compliance.

2.3 Waivers & Deviations

All waivers and deviations from the guidelines of this document require approval from the Space Shuttle Vehicle Engineering Office.

3.0 APPLICABLE DOCUMENTS

The applicable documents relevant to this Guideline and the Electric Auxiliary Power Unit (EAPU) Design and Development Program include, but are not limited to the following:

MILITARY

MIL-STD-461D	Requirements for the Control of Electromagnetic Interference Emission and Susceptibility
MIL-STD-462D	Test Method Standard for Measurement of Electromagnetic Interference Characteristics
MIL-W-22759 SUPP1	Wire, Electrical, Fluoropolymer, Insulated Copper or Copper Alloy
MIL-STD- 1686 Revision C	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
MIL-C-5015G SUPP1	Connector, Electrical, Circular threaded, AN Type, General Specification For
MIL-C-38999J SUPP1	Connector, Electrical Circular, Miniature, High Density Quick Disconnect (Bayonet, Threaded and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification For
NSTS 37330	Bonding, Electrical, and Lightning Protection for Aerospace Systems.(Previously MIL-B-5087)
NSTS 07636,	Space Shuttle Lightning Protection, Test and Analysis Requirements – Revision G
MIL-STD-463	Definition and System of Units, Electromagnetic Interference Technology
MIL-STD-464	Electromagnetic Environmental Effects, Requirements for Systems, March 1997
MIL-STD-810E	Environmental Test Methods and Engineering Guidelines
MIL-W-5088L	Wiring, Aerospace Vehicle
MIL-STD-1818A	Electromagnet Effects Requirements for Systems
MIL-STD-454N	General Requirements for Electronic Equipment, April 1995
MIL-STD-704A	Electrical Power, Aircraft, Characteristics and Utilization of-For Buses

MIL-HDBK-419A, Vol. I	Grounding, Bonding, and Shielding for Electronic Equipment and Facilities Basic Theory
MIL-HDBK-419A, Vol. II	Grounding, Bonding, and Shielding for Electronic Equipment and Facilities, Applications
AFSC DH 1-4	Electromagnetic Compatibility (Design Handbook Series 1-4)
AFWAL-TR-88-4143	Design Guide: Designing & Building High Voltage Power Supplies Vol 2
MSC-SPEC-Q-1A	Clamping of Electrical Connections, Requirements for
SL-E-0001	Electromagnetic Compatibility Requirement Specification
SL-E-0002E	Electromagnetic Interference Characteristics, Requirements for Equipment for the Space Shuttle Program

BOEING

MF0004-002C (Sequence C06)	Electrical Design Requirements for Electrical Equipment on the Space Shuttle Vehicle
MF0004-100	Mechanical Orbiter Project Parts List
MF0004-400	Electrical, Electronic, and Electromechanical Orbiter Project Parts Requirements
MA0110-301	Product Cleanliness

NASA

MSC-SPEC-Q-1A	Manned Spacecraft Center NASA Crimping of Electrical Connections Specification
NASA NSTS 5300.4 (1D-2)	Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program
NASA-STD-8739.3	Requirements Solder / Electrical Connections
NASA-STD-8739.4	Requirements Cabling and Crimping
NASA-STD-8739.1	Requirements for Staking and Conformal Coating of Printed Wiring Boards and Assemblies

NPD-8730.2	NASA Parts Policy
IPC-D-275	Design Standard for Rigid Printed Boards and Rigid Printed Board Assembly
IPC-D-6011	Generic Performance Specification for Printed Boards
IPC-D-6012	Qualification and Performance Specification for Rigid Printed Boards
ASTM-D-1868	Detection & Measurement of Discharge (Corona) Pulses and Evaluation of Insulation Systems
ASTM-D-3382	Measurement of Energy and Integrated Charge Transfer Due to Partial Discharges (Corona) using Bridge Techniques
MSFC-STD-531A (TBD)	High Voltage Design Guideline (Previous MSFC-STD-531-1978)

3.1 Order of Precedence

In the event of a conflict between the text of this document and the applicable documents cited herein, the text of this document shall take precedence. In the event of conflict between the recommendations of this specification and a requirement explicitly stated in either the applicable equipment specification or the applicable equipment contract, the requirements of the procurement specification or contract shall take precedence over the recommendations of this document.

4.0 INTRODUCTION

There are a variety of electrical interactions that may occur between a space power system and its environment that can result in damage to the system or degraded mission performance. These generally fall into two classes:

- Gas breakdown phenomena include corona, partial discharge, and Paschen breakdown. In some cases, sustained arc discharges are possible. These are associated with environments characterized by low-pressure gas, resulting either from venting, outgassing, or in some cases by-products of the arcs themselves when the fields (applied voltage) exceed a critical electrical breakdown voltage for the given system. It should be noted that any corona initiation event might be a precursor to a fully developed electrical gas breakdown especially in high current systems such as in the EAPU. This may lead to a "plasma torch" fed from the EAPU batteries, resulting in significant damage to the system. Therefore, corona should be prevented by adequate insulation.

- Plasma interactions occur when all gas has been largely removed, leaving the ambient space environment. In Low Earth Orbit (LEO), this is an atomic oxygen plasma that reaches its maximum density at the altitudes typical of STS operations. Long experience with high voltage interactions with this environment has shown that space power systems are vulnerable to arcing and parasitic power loss. Additionally, current collection from such plasma results in the entire vehicle shifting its floating potential with respect to the ionosphere. While plasma interactions are best known with respect to solar arrays, any high voltage conductor exposed to a plasma environment will interact with it.

4.1 Gas Breakdown

Corona and micro-discharges within an electric-power system generate spurious high-frequency pulses that may produce interference in communication links and malfunctions in sensitive electronic circuits. Corona and micro-discharges also degrade insulation in the vicinity of the discharge, reduce distribution efficiency, disassociate some gases creating noxious gases and odors, and can cause ignition of volatile gases.

Corona between electrodes and insulated conductors occurs whenever the voltage gradients in a non-uniform field exceed a critical value. The voltage above this critical voltage usually is refereed to as "high voltage." In general high voltage is the voltage above which electrical breakdown (or gas discharge) is likely to occur. The level of this high voltage differs for each electrical component/system based on the physical structure of the system, characteristics of the operating electric field, and the environment in which the system is operating.

Corona is detected as a luminous glow or a parasitic current occurring between the electrodes due to these localized critical gradients. Further, it may develop into a spark or an arc resulting in larger currents. The initiation of electrical discharges (including corona) in gases follows Paschen's law, which states that the breakdown voltage is a function of gas pressure (density) times effective electrode spacing, *pd*. Based on Paschen's law, corona initiation voltage data have been presented for various gas and gas mixtures either as functions of gas pressure multiplied by effective electrode spacing or as functions of gas pressure for various electrode, wire, or connector configurations at constant temperature.

Partial discharges in an electrical circuit or component generate noise, which propagates to connected equipment. Typically, the noise signature (frequency range) is 15 kHz to 200 MHz. If the partial discharges are extensive, then noise can also be induced in low-interference threshold circuits in the immediate vicinity. In high-frequency systems such as radar, the wave shapes of the electrical signals can have partial discharge signals superimposed onto the equipment's output signals.

These partial discharges produce ozone, optical emissions, and corrosive species, which cause deterioration of dielectrics. If corona persists for several hours, direct or accumulated time, the dielectric may start to deteriorate and eventually a breakdown will result

A system operating at 270 Vdc with transients less than 320 V-peak will not experience corona and glow discharges between bare and thinly coated electrodes in air at atmospheric pressure (760 Torr). However, electrical transients exceeding 320 volts peak in air or contaminated nitrogen may experience partial discharges, glow, and corona in the critical Paschen minimum region. Pure helium, nitrogen, and hydrogen atmospheres have lower corona initiation voltages, as seen in Figure 1, and systems operating in these environment require special attention to corona discharges. Hydrogen rich atmospheres are potentially ignitable when combined with the residual air and outgassing products in the vicinity of a discharge. Discharges and corona may be avoided by utilizing proper encapsulation, shielding, or pressurization techniques.

Systems operating at 28 V do not constitute a corona concern until the operating frequency approaches the GHz range. 115V, 400 Hz, 3-Phase systems require protection for transients over a 180 V-peak. Usage of high frequencies in subsystems or systems may constitute corona concerns, and need to be evaluated for corona prevention. Surface creepage and flashover across insulating surfaces, printed circuit boards, and electronic components may also be a concern in these systems and considerations for spacing of conductors should be addressed.

4.2 Plasma Interactions

In addition to the gaseous environment associated with the Orbiter Aft Fuselage compartment, the use of high voltage requires consideration of the plasma environment characteristic of low Earth orbit (LEO). If there is no venting or leakage and gas pressure is very low, approaching orbital ambient pressure, corona and partial discharge will not be an issue. From the point of view of electrical interactions, the chief concern is that the local environment in the aft fuselage includes an ionized component from the ambient ionosphere.

Plasma densities in LEO vary with altitude, orbital inclination, dayside or night, time of year, and sunspot cycle. To first order, the vertical structure is conventionally described in terms of four layers that, in order of increasing altitude and increasing plasma density, are designated D, E, F1, and F2. Table 4.1 shows nominal plasma densities for these layers. Orbiter operation normally occurs near the peak of the F2 layer.

Region	Nominal Height of Peak (km)	Plasma density At Noon (cm^{-3})	Plasma density At midnight (cm^{-3})	Dominant Ion
D	90	1.5×10^4	vanishes	O_2^-
E	110	1.5×10^5	1×10^4	O_2^+
F1	200	2.5×10^5	vanishes	O^+
F2	300	1.0×10^6	1.0×10^5	O^+

Table 4-1 Nominal Properties of Ionospheric Layers

When energized conductors are exposed to plasma, positive surfaces collect electrons while negative surface collect ions. The Poisson equation governs charge movement. Electrons, which are much lighter and more mobile than ions, are collected more easily. Surfaces therefore charge to whatever potential they must in order for the net current flow to be zero in equilibrium. A current loop results that uses the ionosphere as part of the conducting path. The potential that any given surface will achieve is very difficult to model and generally requires full-up testing in a plasma environment. The resulting interactions may be summarized as follows:

- Surfaces that are negative with respect to their surroundings are subject to arcing. These arcs may be plasma arcs or they may be arcs to adjacent conductors. They are generally a momentary discharge of accumulated energy, lasting only milliseconds, but under some conditions may be sustained. The necessary conditions are for the current and voltage to be maintained above threshold values. Plasma arc thresholds are poorly known but may be as low as 50 V.

- Surfaces that are negative are subject to ion bombardment and sputtering. Since the dominant ion is atomic oxygen, care must be taken that chemical attack does not occur as well.

- Surfaces that are positive can easily collect sufficient electrons to present a measurable power drain to the system. Generally referred to as "parasitic current collection," this effect can result in a few percent power loss to the system.

- If the power system is negatively grounded, as in most commonly done, the entire vehicle can float negative with respect to the ionosphere. For systems with very large areas of high voltage surfaces, such as the International Space Station, this effect is large, and requiring a plasma contactor to mitigate. Experience with high voltage experiments in the Orbiter payload bay indicates that significant charging of the orbiter does not occur. Generally, the large area of exposed metal presented by the main engine bells collects sufficient ion current to balance at a low potential. If a system, such as the EAPU, is completely isolated from the orbiter body, plasma interactions will result in the system itself floating negative with respect to the orbiter. The magnitude of these effects is difficult to quantify in advance, but should be addressed in the design.

- High frequency cables and components present an additional complication. For frequencies of a few tens of kilohertz, as proposed for EAPU, electrons can respond to the changing field but the massive ions cannot. Cables under these conditions can be charged to a potential equal to the rms voltage in the cable. Standard shielding practice, if followed properly, eliminates this problem.

4.3 System Packaging

There are four basic approaches to packaging EAPU subsystems for environmental compatibility that address the issue of high voltage interactions described above. Two of these involve a complete enclosure of the entire system and eliminate all interactions. The other two require component level design and modification.

- **Pressure vessel** – If the mass associated with a hermetically sealed pressure vessel is acceptable, the electric APU may be sealed in one atmosphere of air. Since available components have been optimized for this environment, no interactions problems will occur either with plasma or with neutral gas. This approach suffers chiefly from the considerable mass involved as well as additional costs, and complications in between-flight processing.

- **Non-pressure enclosure** – Electronics with exposed conductors are sometimes placed within a grounded metallic conducting enclosure. Since such enclosures are vented and designed for vacuum operation, their mass and required structural strength is considerably less than for a pressure vessel. To implement this approach, two additional measures must be taken. One to eliminate plasma interactions and the other to avoid breakdowns.

  To avoid gas breakdown, an additional purge system integral to the EAPU will be needed. The orbiter purge with Helium offers results in a high probability of corona and partial discharge, as discussed in later sections of this document. During those times that the helium purge is active and for some time afterward, helium partial pressures in the enclosure will be in the regime that is optimal for gas breakdown phenomena. Figure 2 and Figure 7 show the corona initiation voltage for helium. One way to eliminate this threat is to have an internal purge within the EAPU enclosure, with a gas that withstands high voltage in all pressure regimes. We recommend CO_2 for this purpose. As shown in Figure 3, its Paschen minimum is approximately 400V.

  To avoid plasma interactions, care must be taken that plasma does not enter the enclosure and react with exposed conductors inside. The key requirement on such systems is that all openings must be smaller than the plasma Debye length, which in turn depends on the plasma density and temperature. One can readily estimate the maximum opening consistent with such a requirement.

  The plasma will be capable of maintaining electric fields over a distance of approximately one Debye length λ_D, which is given by

  $$\lambda_D = (kT_e/4\pi ne^2)^{1/2} = 7.43 \times 10^2 (T_e/n)^{1/2}$$

  where T_e is the electron temperature in eV, k is the Boltzmann constant, $\pi = 3.14159...$, e is the charge of the electron, and n is the electron density in cm^{-3}. Placing representative values from International Reference Ionosphere (IRI-86) simulations in the above equation, one finds a minimum Debye length from 0.12 cm at 1100 K to 0.17 cm at 2300 K.

Openings in the experiment electronics enclosure must have smaller dimensions than this minimum to prohibit plasma interactions with the experiment electronics. Larger openings may be used if covered with an electrically connected conductive wire mesh of spacing less than the minimum Debye length. To provide a reasonable margin of safety, a general guideline is that no opening should exceed .10 cm in its largest dimension.

If this approach, a grounded, conducting, vented enclosure with all openings screened and equipped with a CO_2 purge, is taken no interactions problems will occur either with plasma or with neutral gas.

- **Coating, potting, sealing, and shielding** – If not placed in a sealed enclosure, design could still proceed with a determined effort to insulate, conformal coat, and pot all high voltage surfaces in such a way that no bare energized conductors are exposed to the environment. High frequency cables must be shielded to prevent plasma induced charging. If comprehensive, such an approach will eliminate high voltage environmental interactions with neutral gas and plasma. Its drawback lies in the fact that such coatings become potential failure points as systems age.

- **None of the above** – If none of the above approaches is taken, EAPU components including high voltage surfaces will be exposed to the neutral and plasma environment. Each component, cable, and connector must then be considered on a case-by-case basis and criteria for materials selection, design, or the selective use of coating invoked as appropriate. Since modifications to the design process are now made only where determined to be absolutely necessary, this is the most general approach and is the one assumed in this document.

Figure 4 through Figure 7 show data points taken for corona initiation voltages for helium, helium mixtures, and oxygen environments.

5.0 ENVIRONMENTS

5.1 Temperature

The operating ambient temperature environments range from minus 50 °F to 150 °F.

5.2 Pressure

The operating ambient pressures range from 15.23 psia (788 Torr) to $1x10^{-10}$ Torr (as specified in the EAPU-Systems Requirements Document)

5.3 Aft Fuselage Atmosphere

Prelaunch thru T-31 sec

Nitrogen - Purge dominates the atmosphere 100% nitrogen with trace (40 ppm) argon

Hydrogen - Leakage from the MPS results in typical hydrogen concentrations up to 300 ppm. Hydrogen upper limit for launch is 600 ppm.

Oxygen - Some oxygen leakage can also occur, but this is not as common as hydrogen. Oxygen upper limit for launch is 500 ppm.

Helium - Helium concentration up to 5% can also occur. 12,000 – 15,000 ppm typical, 50,000 ppm is a good upper bound

T-31 sec thru Ascent

Aft fuselage vent door sequence begins at T-25.4 seconds. Aft fuselage vent doors open at T-15.2 sec reducing positive pressure to local ambient conditions.

After lift off, atmosphere flows out the vent doors as ambient pressure rapidly drops. Some air intrusion is typically observed resulting in a 2 – 4% concentration of oxygen in the aft compartment. MPS system helium venting is also observed as a variable but increasing in concentration. Small amounts of hydrogen, <1%, are also observed but are well below the flammability limit.

Orbit

Vacuum conditions plus outgassing products, purging, and leakage. Plasma environments typical of LEO.

De-Orbit burn thru 5300 fps

Vacuum and plasma conditions plus outgassing products, purging, and leakage.

5300 fps thru 2400 fps

Helium - MPS helium bottle is dumped at 5300 fps. Vent doors are closed during this timeframe. Helium generates an atmosphere up to 0.5 psia (25.8 Torr).

2400 fps thru rollout (6 min before landing)

Ambient Air - Vent doors open at 2400 fps (ambient pressure is about 0.2 psia (10.3 Torr) allowing ambient air to fill the aft fuselage.

6.0 GENERAL REQUIREMENTS

Mission Profile: From **End Item Specification – Preliminary Version, 7/27/99,** Electro-Hydraulic Unit for the Orbiter EAPU.

REQUIREMENTS

Requirements described in following paragraphs are defined in terms of flight hardware requirements. Prototype hardware design shall meet these requirements except where specifically stated as not applicable to prototype hardware. Flight hardware is considered a follow-on generation design from the prototype. Contractor shall provide supporting rationale for how the prototype design is a logical step towards flight design including a migration path.

Nominal Mission and Operational Timeline (does not include abort modes) *

The EAPU shall deliver hydraulic power that will meet the mission power profile that consists of prelaunch, ascent, orbit flight control system checkout, descent, and ground turnaround operation (as specified in the EAPU Systems requirements Document) *. Mission phases are defined in terms of their applicability to the EAPU.

Prelaunch *

This is the phase that precedes Space Shuttle launch. A number of EAPU related electrical checkouts are performed in the 12 hours prior to launch. Each of the three EAPUs are activated 5 minutes prior to the planned liftoff time. Aerosurfaces and gimbal actuators are moved prior to launch to verify performance of the hydraulics, actuators, EAPU, and commanding systems. Nominal runtime before launch is 5 minutes, but holds can extend the runtime to a maximum of 11 minutes before other constraints will result in a launch scrub.

Ascent *

This is the phase where the Orbiter travels from the launch pad and achieves an orbital altitude. The ascent phase begins at liftoff and lasts for 15 minutes with EAPU shutdown occurring at the conclusion.

Orbit *

This is the phase following ascent and before the de-orbit burn event. Duration may reach a maximum of 21 days. The EAPU is operated only for checkout purposes during this timeframe. Checkout occurs one or two days prior to planned descent and includes 5 minutes of APU operation while aerosurfaces are moved to verify actuator and commanding systems.

Descent *

This is the phase of returning from Orbit through landing. EAPU operation is required for a total of 50 minutes during this phase. The orbiter maneuvering system de-orbit burn is completed to reduce Orbiter velocity before the EAPUs are activated. EAPU start occurs 8 minutes prior to entry interface (EI). EI occurs at an altitude of 400,000 ft. The EAPUs continue to operate as Orbiter altitude decreases through landing and wheelstop. EAPU shutdown occurs after wheelstop. Approximately 20 minutes later, the EAPUs are started for 2 minutes to support repositioning of Space Shuttle Main Engine Nozzles.

* For up-dated mission profile time sequence and duration information, refer to the EAPU – SRD latest version.

Ground Turnaround **

This is the phase between Orbiter flights. A ground DC electric power supply will be provided for the EAPUs allowing operation to support testing, support servicing, and allow movement of aerosurfaces for vehicle repair and maintenance operations. The battery will be isolated from the EAPU during ground operation. The electric APU will also be operated to remove air from the hydraulic system

** ground portion is not applicable to the prototype EAPU hardware.

Power Requirement

A battery will be the power source for each of the three EAPU systems. Each battery will be capable of producing 240 – 320 Vdc output over a 91 minute mission profile that includes 25 to 30 kW average continuous power with 125 kW peaks reaching 2 seconds duration.

7.0 CABLING

7.1 Vehicle Requirements

Proper wiring and shielding design for corona prevention shall be employed. This includes selection of wire size, wire type, insulation type, insulation thickness, and termination techniques to be conducive with a helium rich environment. Shielded cables are required for conductors having less than 5 mils insulation or conductors that lay in open cable trays and all cables carrying frequencies above 10 kHz.

7.1.1 Materials

Insulation shall be sufficiently thick to inhibit corona in a helium rich environment regardless of spacing between high voltage conductors and ground, or low voltage conductors.

7.1.2 Separations, Routing, & Placement

Corona susceptible conductors operating in helium, hydrogen or oxygen rich atmospheres should not be routed in parallel to minimize wire contact and coupling. Conductor spacing should be maximized, and conductors should be separated with barriers to suppress corona and arcing. Similar considerations shall be made for placements of terminal blocks, bus bars, splices, or any other terminations.

Examples of hydrogen or oxygen rich atmospheres include, but are not limited to, the following:

- Around high-probability leakage points
- Hydrogen or oxygen feedlines and/or vent lines

There are no specific restrictions for 28 Vdc wiring separations and routing.

7.2 Interconnecting Cable and Internal Harnesses

It is important to note that the guidelines stated herein are in addition to, and take precedence over, MIL-W-5088.

The insulation material characteristics (i.e., mechanical, electrical, thermal, and chemical), insulation thickness, surrounding air gaps, temperature, and pressure all contribute to the determination of the minimum wire corona initiation voltage. A single unshielded wire in an open cable tray will have much higher probability of corona over a long time duration. This is due to the air gaps that extend from a very small spacing between the wire insulation and a ground plane to the very long air gap that will exist between the top of the wire insulation and the furthest ground plane.

The wire insulation shall be inserted inside the connector grommet to preclude the air gap between the conductor and the ground surface, or connector shell or other wire conductors. To preclude air gap formation between the conductor and the connector shell, design consideration shall include wire insulation shrinkage tolerance as determined by the normal shrinkage following 10 thermal cycles from –55°C to 260°C, with a two-hour soak at each temperature extreme.

For corona susceptible wiring applications, wire selection should be Teflon/glass for wire sizes AWG18 and larger, or Teflon for wire sizes smaller than AWG18, in accordance with MIL-W-22759 to withstand temperatures up to 260^{O} C ($500\,^{O}$F).

When two or more wires are attached to two or more terminals or to several connector pins, the individual wires will be physically separated (Figure 8). The separation (or spread) between wires should be kept as small as possible, and the length of the spread shall be kept as short as possible. The length 'L' shall be less than 3-times the distance 'S'. A wire tie is recommended so the wire bundle does not flare or separate. **Note:** High-Voltage Wire Ties shall be in accordance with Figure 9.

Wire bend diameter should not be less than six radii.

Interconnecting cables should be shielded and appropriately grounded with metal or graphite-filled aramid fiber (graphite fiber interwoven in Kevlar). Cable ties and clamps shall be designed to avoid chafing or cutting the wire insulation. Cable trays or guideways shall be free of sharp projections and edges.

7.3 Wire Terminations

When providing wire terminations, sharp surfaces and pointy extrusions shall be avoided. Examples are provided in Figures 10, 11, and 12.

For corona-susceptible equipment, wire terminals shall be either coated with at least 5 mils silicone rubber, or equivalent material, or employ a tight fitting rubber boot to reduce the probability of surface tracking and corona. An equivalent shrink-fit tubing may be applied provided it is a high temperature material that will not loosen after at least 10 temperature cycles in the range of –55°C to +260°C, with a two-hour soak at each temperature extreme.

8.0 CONNECTORS

Connectors rated for several hundred volts may fail for spacecraft use at lower than rated voltages, because there exist low-pressure environments and gases around the pins and sockets and across the insulation interfaces. Also, when a connector backshell is potted, gas may be trapped, and this gas may be a precursor to corona conditions for high voltage applications.

Connectors should be selected in reference to MIL-C-5015 and/or MIL-C-38999. Where wire sizes allow, either type connector can be used, however the MIL-C-38999 is recommended. It is recommended that all corona susceptible connector backshells in gaseous environment containing more than 5% helium should be potted.

Not more than one wire should be routed through any hole in the grommet of an environmentally sealed connector as per MIL-STD-454 Sec. 10, paragraph 4.10.

When an insulated wire is inserted into a connector, the connector grommet material should cover a portion of the wire insulation to eliminate an air gap between the conductor and the ground surface or another wire conductor (Figure 13). It should be observed that the insulation shrinkage would not pull the insulation beyond the confines of the grommet, allowing an air gap to exist between the conductor and the outer surface of the grommet.

8.1 Bulkhead Connectors & Feedthroughs

It is recommended that all corona susceptible connector backshells in gaseous environment containing more than 5% helium should be potted.

8.2 Terminations

Terminations shall be in accordance with section 7.3.

8.3 Standoffs and Feedthroughs

Standoffs and feedthroughs should be solder-balled. The radius of the solder ball facing the ground plane should be at least 1/6 the value of the spacing between the solder ball and ground plane or adjacent high voltage circuit. This low ratio decreases the voltage gradient at the surface of the solder ball and decreases the probability of corona. When large spacings are involved the solder ball should have at least 3.1 millimeters (0.125 inch) diameter. These solder balls must be properly secured to eliminate any dynamic vibration and acoustic problems. See Figures 14 and 15. Following soldering, the joint should be potted.

9.0 ELECTRICAL / ELECTRONIC COMPONENTS AND SWITCHGEAR

9.1 Solid Insulation

This section provides information relevant to insulation materials and processing techniques for high voltage electronic components.

9.1.1 High Voltage Conformal Coating

Conformal coating is the application of multiple individual coats of low viscosity liquid insulation to a circuit or printed circuit board in which each coat is cured resulting in a solid coating, which is free of voids, blisters, and cracks through the layers on all components and wires.

All boards, conductors, wiring, and electrical components must be cleaned per the appropriate specification before the unit is conformally coated. This includes solder flux, finger prints, and particles from the work bench and dust.

The circuit board should be conformally coated with at least three separate layers of a low viscosity insulation. Application may be either by dipping, brushing, or spraying with each layer applied at right angles to the preceding layer. The three layers are necessary to eliminate voids, blisters, cracks, or continuous leakage paths, and any uncoated areas that normally occur in single or double coating processes. The completed process should be checked by an insulation test.

Paraylene conformal coatings are adequate for all pressurized electronic equipment. Polyurethane, or equivalent, coatings may be preferred where thicker coatings are required.

9.1.2 Encapsulation (Potting)

Encapsulation (potting) is the immersion of all electrical components, circuits, and printed circuit boards into a liquid insulation which, when cured, is a void-free solid insulation.

The encapsulated volume should be kept small without jeopardizing the electrical integrity of the encapsulant. When large volumes are required, the volume should be long and narrow. This reduces the probability of internal mechanical stresses which can result in component-to-component cracks. Volumes with physical dimensions greater than one inch wide and two inches deep, and several inches long may have many internal cracks.

All components, boards, and wiring must be cleaned of particles, grease, finger prints, non-cohesive materials, and solder flux prior to encapsulation.

Solid encapsulation must be void-free throughout to be effective. Three methods of void-free encapsulation are vacuum impregnation, centrifugal acceleration, or a combination of the two.

Final encapsulation of high voltage interconnecting wiring and terminal parts must be done very carefully. The wires must be properly fixtured so they are not pulled or twisted or otherwise disturbed during or following the proper curing process.

An adequately encapsulated high voltage circuit has all the inter-space between electrical components, wires, circuit boards, and ground planes filled with a homogenous solid insulation.

Sometimes a poor bond can exist between a newly applied insulation and an insulation of the same type, which has been oxidized or has shelf degradation. The materials bonding to the components must be verifiable by testing.

9.1.3 Uninsulated Circuitry

Uninsulated circuitry is not recommended, among others, mainly for the following reasons:

1. Materials migration is enhanced across open faced circuit boards.
2. Surface creepage and flashover potential is enhanced.
3. Some bare metallic surfaces, when oxidized by thermal aging, have lower corona and breakdown voltage than a coated or encapsulated surface.

9.1.4 Insulation Life

The estimated insulation life of an insulating material is based on the electrical properties, temperature, the applied voltage stress and duration, and the workmanship of the material's application. The insulation will withstand voltage stress for several years if the maximum voltage gradients within the material are kept very small (less than 800 volts/millimeter, or 20 volts/mil). This requirement increases the insulation weight. If the weight of the EAPU system becomes an issue, then the insulation life should be plotted for each insulation as a function of life vs. voltage stress and/or life vs. insulation thickness for the Orbiter mission parameters and reassessed accordingly.

9.2 Relays and Circuit Breakers

Relay, contactor, and circuit breaker devices in non-pressurized compartments should be sealed to maintain a gas environment, which will inhibit breakdown and corona. This will serve to eliminate the probability of voltage transients from breaking down the gas between the closely spaced contacts, and the intrusion of helium and hydrogen gas molecules into the components. These devices shall maintain seal integrity when exposed to pressures simulating LEO environment. Devices, which have external post type or lug terminals, shall have the terminal posts potted with 5 mil minimum of approved insulation and/or incorporate terminal boots.

9.3 Components

9.3.1 Transformers

Encapsulated transformers, when required, shall be in accordance with Section 9.1.2.

Flat-pack transformers (very high frequency transformers greater than 10 kHz) are designed with very small spacing between the printed circuit card windings and the ferrite cores. These transformers shall be insulated with no less than 10 mils of a silicone or appropriate high-temperature, low-pressure conformal coating material to inhibit partial discharge and corona activity. Material selection of ferrite cores should consider Curie temperature limitations to avoid the possibility of degradation.

Encapsulated flat-pack transformers surrounded with either a pure gas or a gas mixture of helium or hydrogen should be either potted void-free or pressurized to retain at least one-half atmosphere (380 Torr) pressure.

Wound transformers and other inductive components (including motors) shall have all windings vacuum impregnated with a material that will withstand the thermal and low pressure environment seen by the EAPU system.

Kapton inside transformers shall not be used.

9.3.2 Capacitors

Capacitor selection shall require the materials of construction to withstand the maximum temperatures of operation and post flight as specified in Section 4. Capacitors fabricated with reconstituted mica or ceramics as the primary internal device insulation should receive primary consideration for use.

9.3.3 Resistors and Diodes

Resistors and diodes shall have solid cores and solid base materials. Hollow cores will allow partial discharges (corona) and/or arcs to be generated from terminal to terminal through the air-filled hollow core. Resistors shall be in accordance with MSFC STD-531 paragraph 6.4.1. (MSFC-STD-531A Section 6.2.1.1)

The alternator diodes shall have a reverse recovery characteristic of T_A/T_B no greater than 2.

9.3.4 Transistors

The electric field stress across the encapsulated surface material between terminals shall be less than 20 V_{peak}/mil. The transistor coating enclosing the solid-state device(s) shall be at least 10 mils thick as determined by non-intrusive testing, such as x-ray examination.

9.4 Electronics Packaging

Electronics packaging should consider the need to provide adequate spacing between subassemblies and parts to maintain insulation integrity and minimize voltage stresses.

A separating insulating film or mechanical barrier should be used to separate high and low voltage circuits and closely spaced printed circuit boards from each other. Ground planes and large adjacent components should be adequately separated in physical space so as to minimize high electric field stresses in air gaps.

The electric field stress between adjacent conductors on a printed circuit board, or equivalent surface, should be less than 20 volts peak/mil. This will inhibit creepage and tracking at high temperature and high frequency in vacuum and high humidity environments. As previously stated, Kapton based insulating materials should not be used.

EMI requirements should be factored into circuit design and packaging design. An excellent EMI design will also suppress some of the partial discharges and corona events. Design and test for EMI and EMC will be in accordance with the following documents:

SL-E-0002E	Electromagnetic Interference Characteristics, Requirements for Equipment for Space Shuttle Program
MIL-STD-462	Test Method Standard for Measurement of Electromagnetic Interference Characteristics
MIL-STD-463	Definitions and System Units, Electromagnetic Interference Technology

When power electronics switching circuits that operate above 10 kHz are required, design details showing adequate packaging provisions should be included to avoid effects of reduced partial discharge and corona inception voltages due to high frequency effects.

All edges shall be rounded where possible. This includes boards, parts, wires, and connections. Rounded implies that the radius of the edge should be greater than 1/4 the spacing between the edge and the adjacent ground or insulated surface.

When electronics enclosures require pressurization, the minimum internal pressure should be 100 Torr @23°C or greater, and the minimum spacing between conductors should be at least 3.75 mils.

For an unpressurized box, all parts, printed circuit boards, and conductors should be conformally coated with at least 5 mils insulation. This insulation thickness shall be determined by non-intrusive testing.

To eliminate all discharges it is recommended to divide the electric field stress between widely spaced electrodes (greater than 1 cm). A thin film or board barrier is sufficient; and the thickness of it is not important, so standard application techniques may be applied. A conformal coating of insulation on all parts and boards will eliminate partial discharges in air, carbon dioxide, nitrogen, and oxygen environments. Helium and hydrogen environments require conformal coatings as well, but must be formed by three layers of coating, and minimum thickness of 0.12 mm of overall coating.

10.0 ELECTRIC MOTORS

Electric motor housings should be sealed to maintain a pressure of one-half atmosphere (380 Torr) of fill gas, and to prevent the introduction of helium or hydrogen gasses into the motor housing. Pressurization will eliminate the probability of gas breakdowns within the motor and motor housing. However, when other design concepts are pursued, the design shall include features to prevent corona and partial discharge effects for the defined environment. The articles should be corona tested to satisfy acceptance criteria. See Section 11 for testing.

11.0 TESTING

Corona testing at operational voltage and pressure in a helium rich environment is recommended for parts and components meeting the following criteria

- All non-pressurized parts or components operating at 270 Vdc ±70 Volts.
- All non-pressurized components utilizing operating frequencies of 10 kHz or higher.
- All non-pressurized parts or components operating in pulse mode with voltages at 270 or higher, and at any pulse duration.

Testing will be in accordance with ASTM-1868: Detection and Measurement of Discharge (Corona) Pulses and Evaluation of Insulation Systems, and will include the pressure regimes where Paschen minimum is covered (entire operating pressure spectrum of the EAPU system). Energizing the test article is preferred over static, applied voltage test, and component by component testing is preferred over integrated EAPU system.

Ideally, a helium rich environment should be defined as a gaseous environment composed of 100% helium, since this is the worst case in terms of corona initiation. In practice, testing may be performed using gas that is "research" grade or higher purity helium environment. For corona concerns, presence of more than 50% helium in the operating environment should be considered as a helium rich environment and care should be taken to prevent corona initiation.

Although there is no data on the effects of hydraulic fluid on the corona initiation, any contamination should be avoided during testing and use of the EAPU, since it is known that contamination would have negative effect on (promotes) corona initiation.

12.0 FIGURES

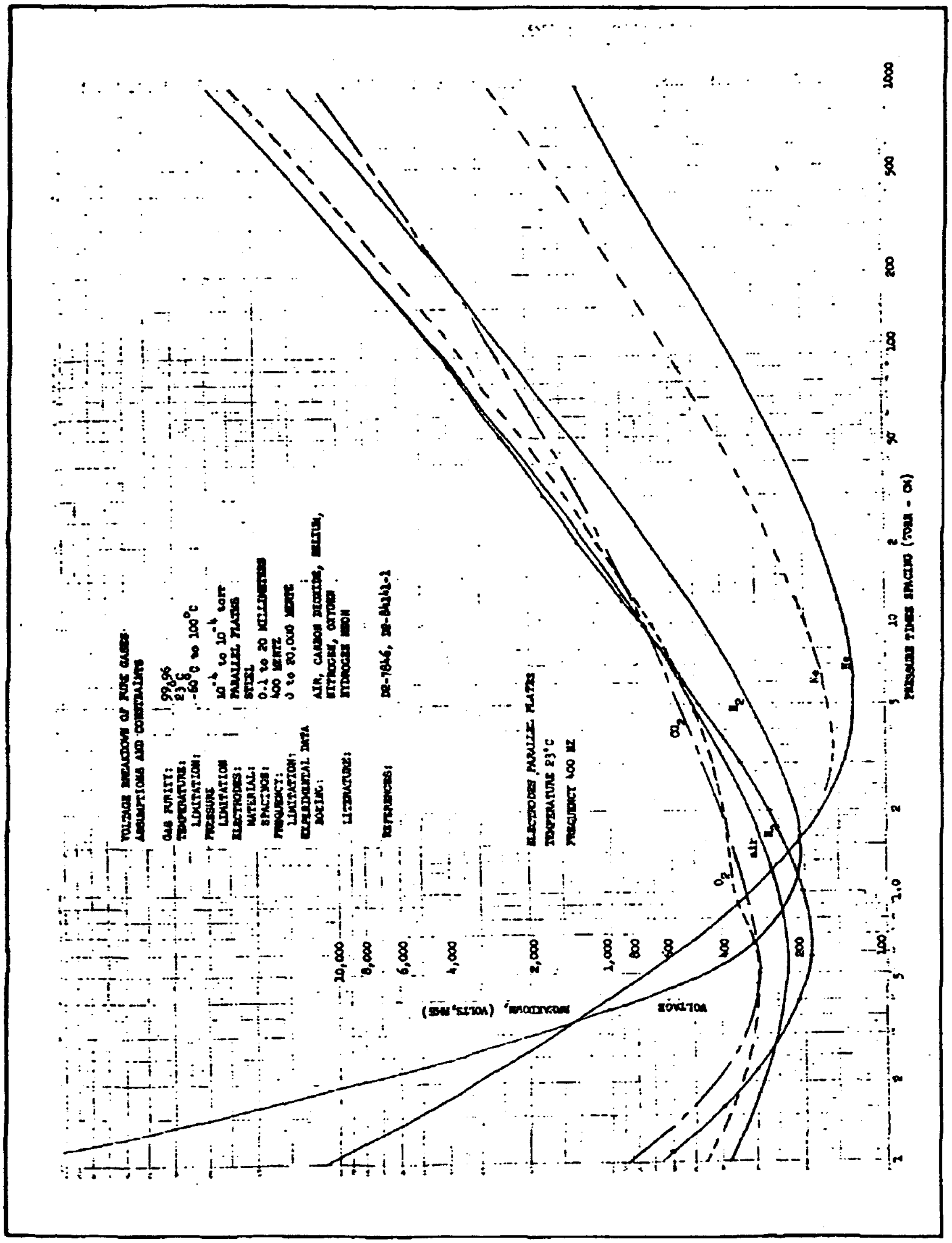


Figure 1. Paschen Curves of several gases at room temperature.

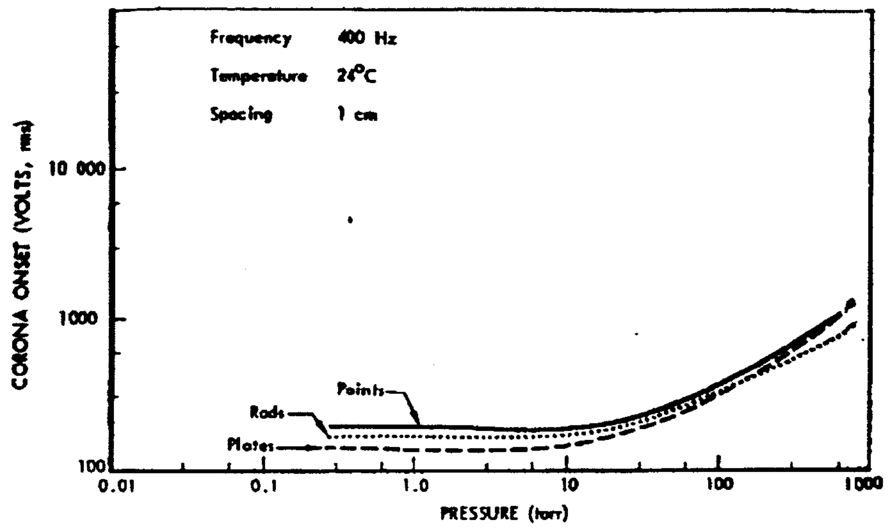


Figure 2. Corona initiation voltage in helium

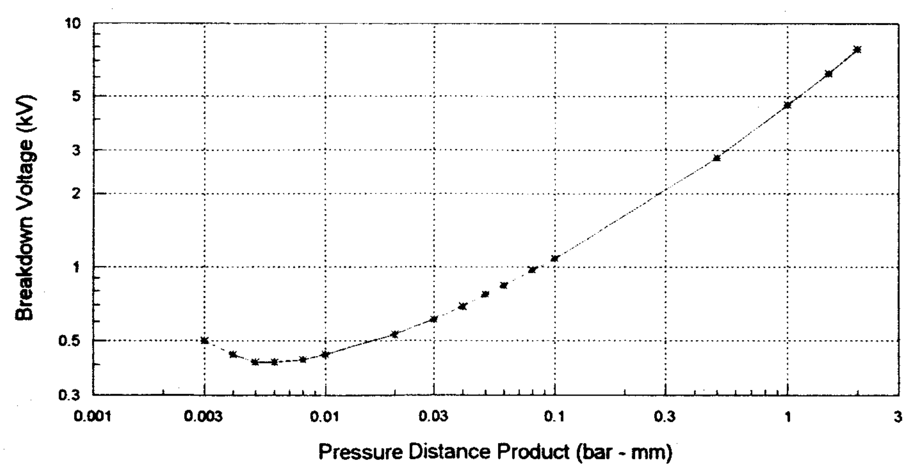


Figure 3. Paschen curve for CO_2

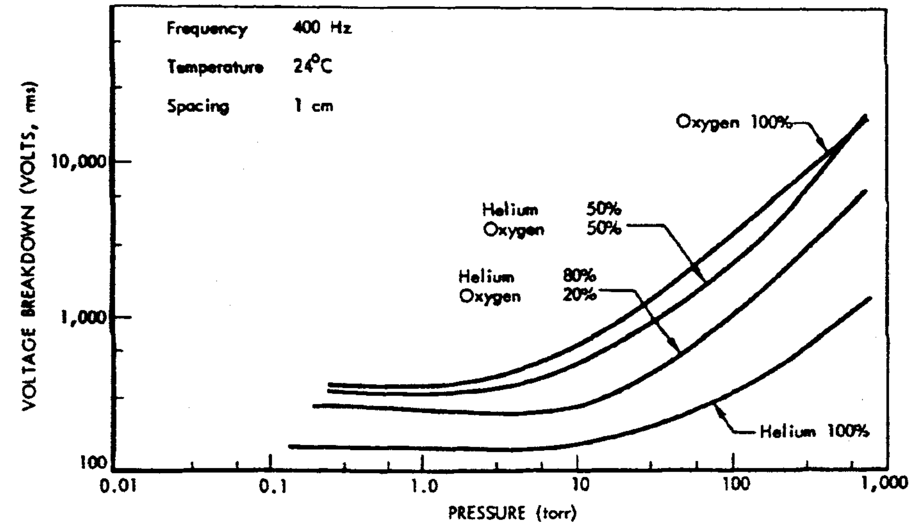


Figure 4. Voltage breakdown of helium-oxygen gas mixtures between 5.0 cm diemater parallel plates.

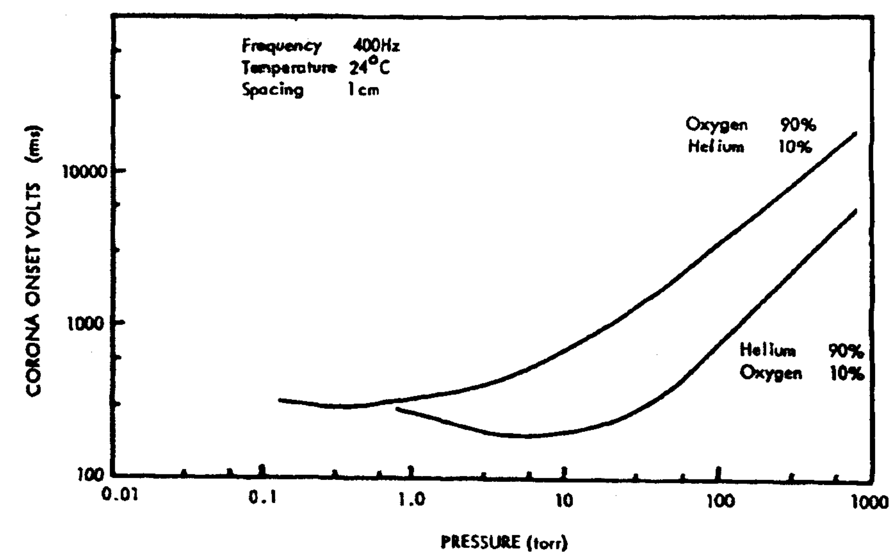


Figure 5. Parallel plates in helium-oxygen mixtures, 90% to 10%.

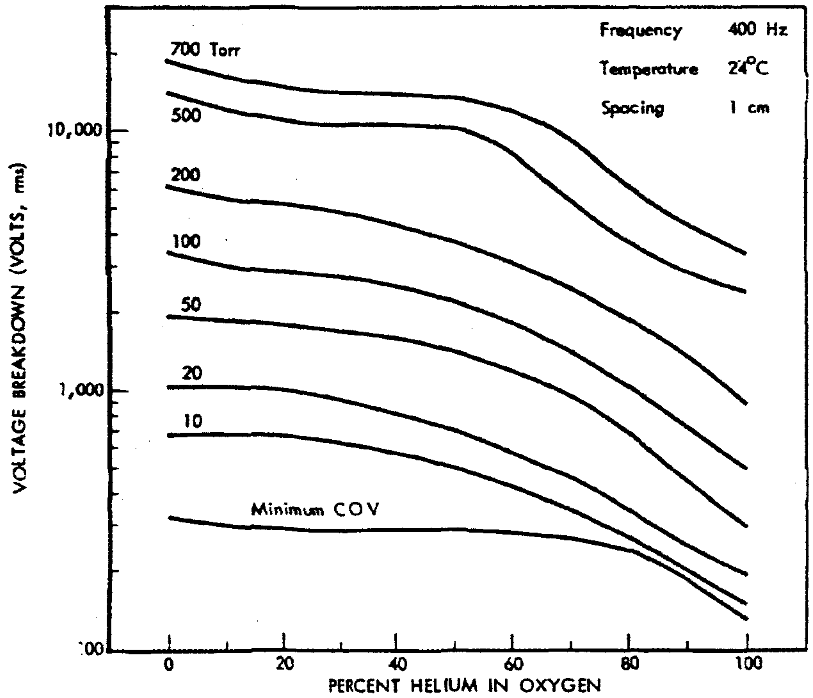


Figure 6. Voltage breakdown of helium-oxygen gas mixtures between 5.0 cm diameter parallel plates.

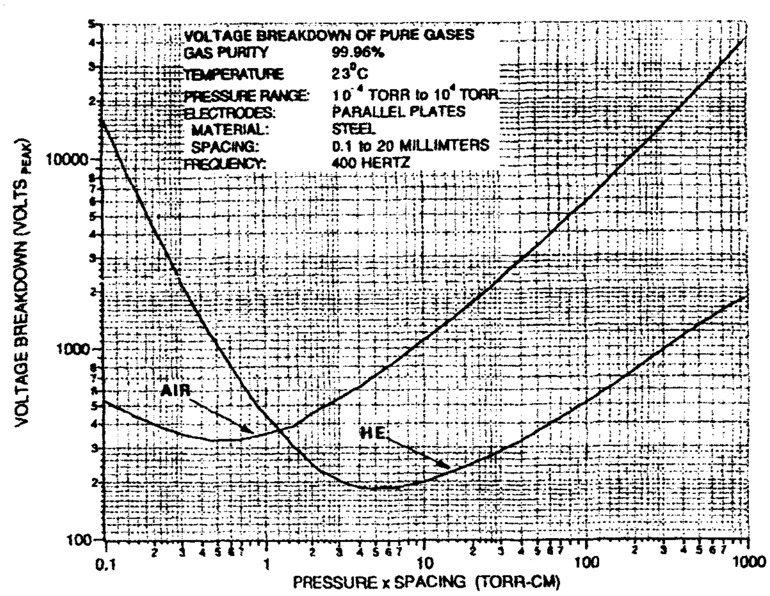


Figure 7. Breakdown voltage of pure heliun and air as a function of *pd* parameter for parallel plate stell electrodes

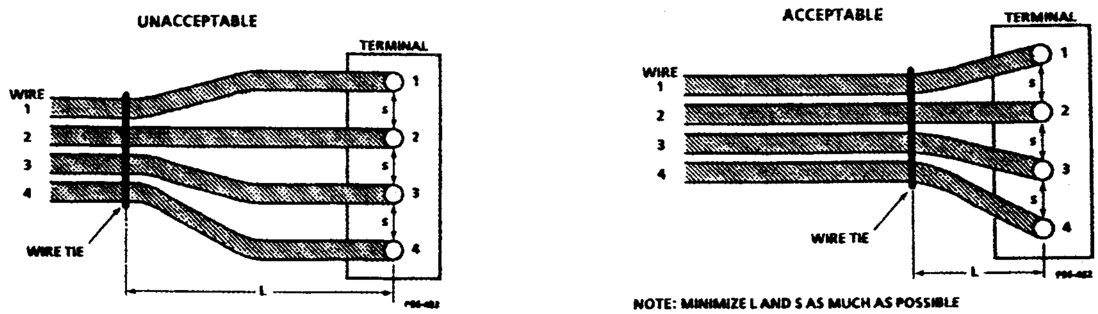
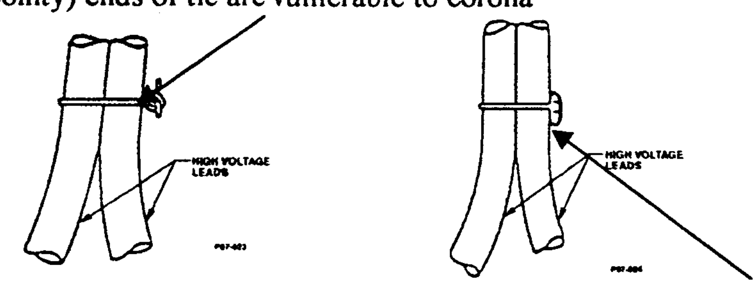


Figure 8: Separation between wires

Note: ¼" Loose (pointy) ends of tie are vulnerable to corona



Note: Bond or fuse tie ends to eliminate sharp points

Figure 9: Proper High Voltage Wire Tie Applications

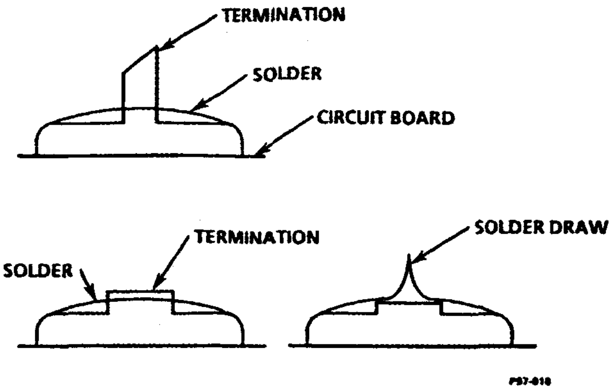


Figure 10: Unacceptable Soldered Terminations

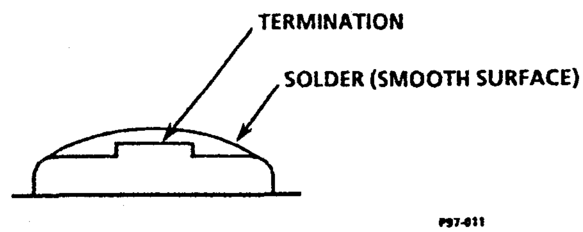


Figure 11: Acceptable Soldered Terminations

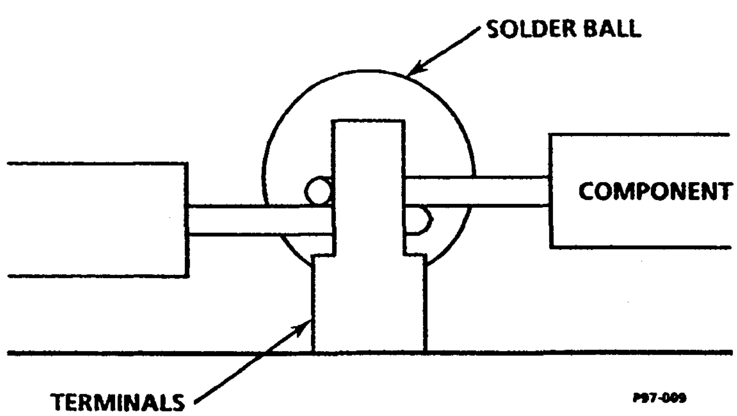


Figure 12: Acceptable Components Interconnection

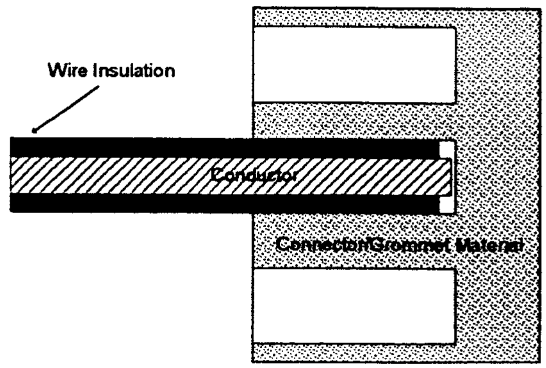


Figure 13. Insulated Wire Inserted Into a Connector

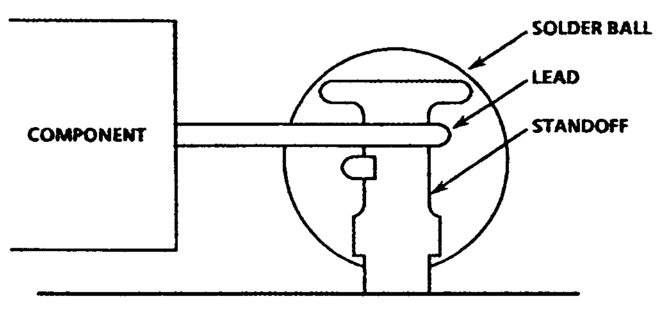


Figure 14. Acceptable Standoff Connection

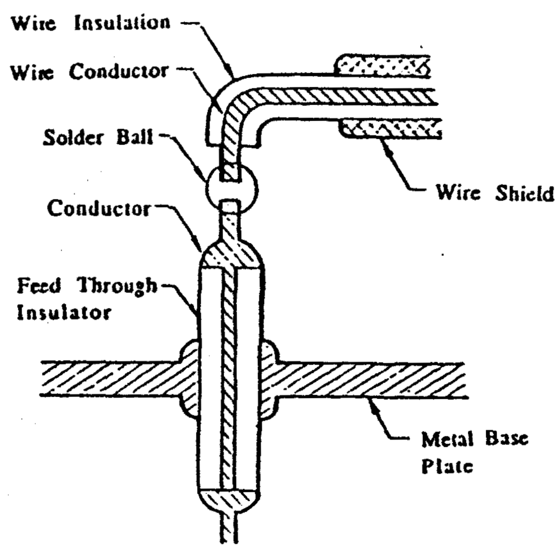


Figure 15. Acceptable Feedthrough Connection

APPENDIX A

Glossary of Terms

*Compiled from AFWAL-TR-88-4143 Vol. 2

Aging	The change in properties of a material with time under specific conditions.
Ambient Temperature	The temperature of the surrounding cooling medium, such as gas or liquid, which comes into contact with the heated parts of the apparatus.
Anode	The electrode through which a direct current enters the liquid, gas, or other discrete part of an electrical circuit. The positively charged pole of an electrochemical cell.
Anti-Oxidant	Substance which prevents or slows down oxidation of material exposed to air.
Arc-over Voltage	The minimum voltage required to create an arc between electrodes separated by an insulating medium under specified conditions.
Arc Resistance -	The time required for an arc to establish a conductive path in a material.
Askarel	Non flammable synthetic liquid dielectric.
Bond Strength	The measure of adhesion between bonded surfaces.
Breakdown (Puncture)	A disruptive discharge through an insulating medium.
Breakdown Voltage	The voltage at which the insulation between two conductors fail.
Capacitance (Capacity)	That property of a system of conductors and dielectrics which permits the storage of electricity when potential difference exists between the conductors. The ratio of the charge on one of the conductors of a capacitor (there will be an equal and opposite charge on the other conductor) to the potential difference between the conductors.
Capacitor - (Condenser)	A device where the primary purpose of which is to introduce capacitance into an electric circuit.

Cathode	The electrode through which an electric current leaves a liquid, gas, or other discrete part of an electric circuit; the negatively charged pole of an electrochemical cell.
Cell	A single unit capable of serving as a d-c voltage source by means of transfer of ions in the course of a chemical reaction.
Charge	In electrostatics, the amount of electricity present upon any substance which has accumulated electric energy.
Conductance	The reciprocal of resistance. It is the ratio of current passing through a material to the potential difference at its ends.
Conductivity	Reciprocal of volume resistivity. Conductance of a unit cube of any material.
Conductor	An electrical path which offers comparatively little resistance. A wire or combination of wires not insulated from one another, suitable for carrying a single electric current.
Contaminant	An impurity or foreign substance present in a material which affects one or more properties of the material
Corona	A non-self sustaining discharge (sometimes visible) due to ionization of the gas surrounding a conductor around which exists a voltage gradient exceeding a certain critical value for a gaseous medium.
Corona resistance	The time that insulation will withstand a specified level of field-intensified ionization that does not result in the immediate complete breakdown of the insulation.
Creep	The dimensional change with time of a material under load.
Creepage (electrical)	Electrical leakage on a solid dielectric surface.
Creepage surface on path	An insulating surface which provides physical separation as a form of insulation between two electrical conductors of different potential.
Critical Voltage (of gas)	The voltage at which a gas ionizes and corona occurs, preliminary to dielectric breakdown of the gas.
Delamination	The separation of layers in a laminate through failure of the adhesive.
Dielectric	A non-conducting material whose conductivity is much smaller that 1.
Dielectric Absorption	The persistence of electric polarization in certain dielectrics after removal of the electric field.

Dielectric Constant (relative permittivity)	Property of a dielectric, which determines the electrostatic energy stored per unit volume for unit potential gradient.
Dielectric Loss	The time rate at which electric energy is transformed into heat in a dielectric when it is subjected to a changing electric field.
Dielectric Strength	The maximum electrical potential gradient (voltage) that an insulating material can withstand without rapture; usually expressed in Volts in per mm of thickness.
Dielectric Test	Tests which consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of insulating materials and spacings under normal conditions.
Disruptive Discharge	The sudden and large increase in current through an insulation medium due to the complete failure of the medium under the electrostatic stress.
Electric Field Intensity	The force exerted on a stationary positive charge per unit charge at a point in an electric field. Designated by E. Also known as electric field strength, electric field vector. For a point charge in space, it is given by $E = \frac{Q}{4\pi\varepsilon r^2}$ where r is the distance from the charge Q and ε is dielectric constant.
Electrode	A conductor, not necessarily metal, through which a current enters or leaves an electrolytic cell, arc, furnace, vacuum tube, gaseous discharge tube, or any conductor of the non-metallic class.
Electron	A stable elementary, negatively charged particle that circles around the center or nucleus in an atom.
Encapsulating	Enclosing an article in a closed envelope of plastic.
Epoxy Resins	Straight-chain thermoplastics and thermosetting resins based on ethylene oxide, its derivatives or homologs.
Filler	A substance often inert added to a plastic to improve properties and/or decrease cost.
Flammability	Measure of the material's ability to support combustion.
Flashover	A disruptive electrical discharge around or over the surface of a solid or liquid insulator.
Frequency	The number of complete cycles or vibrations per unit of time.

Glow Discharge	A nearby luminous neutral plasma of high charge density. A cathode will have a surface glow at low pressure and higher fields, owing to the excitation of the incoming positive ions and neutralization at the surface.
Graded Insulation	Combination insulations with the portions thereof arranged in such a manner as to improve the distribution of the electric field to which the insulation combination is subjected.
Gradient	Rate of increase or decrease of a variable parameter.
Grounded Parts	Parts which are so connected that, when the installation is complete, they are substantially at the same potential as the earth.
Ground Insulation	The major insulation used between a winding and the magnetic core or other structural parts, usually at ground potential.
Hardener	A substance or mixture of substances added to plastic composition or an adhesive to promote or control curing.
Heat Sink	Any device that absorbs and stores energy from a hot object.
Hertz (Hz)	A term replacing cycles-per-second as a unit of frequency.
Hygroscopic	Tending to absorb moisture.
Impedance	The total opposition that a circuit offers to the flow of alternating current or any other time varying current at a particular frequency. It is a combination of resistance R and reactance X, measured in ohms, and designated by, $Z= (R^2 + X^2)^{1/2}$.
Impregnate	To fill the voids and interstices of a material with a compound.
Impulse	A unidirectional surge generated by the release of electric energy into an impedance network.
Impulse Ratio	The ratio of the flashover, sparkover, or breakdown voltage of an impulse to the crest value of the power-frequency flashover, sparkover, or breakdown voltage.
Insulation	Material having a high resistance to the flow of electric current to prevent leakage of current from a conductor-
Insulation Resistance	The ratio of the applied voltage to the total current between two electrodes in contact with a specific insulator.
Insulation System	All of the insulation materials used to insulate a particular electrical or electronic product.

Insulator	A material of such low electrical conductivity that the flow of current through it can usually be neglected.
Ion	An electrified portion of matter of sub-atomic. atomic, or molecular dimensions such as is formed when a molecule of gas loses an electron (when the gas is stressed electrically beyond the critical voltage) or when a neutral atom or group of atoms in a fluid loss or gains one or more electrons.
Ion Exchange Resins	Small granular or bead-like particles containing acidic or basic groups which will trade ions with salts in solutions.
Ionization	Generally the dissociation of an atom or molecule into positive or negative ions or electrons. Restrictively the state of an insulator whereby it facilitates the passage of current due to the presence of charged particles (usually induced artificially).
Laminated Plastics	Layers of a synthetic resin-impregnated or coated base material bonded together by means of heat and pressure to form a single piece.
Lamination	The process of preparing a laminate. Also any layer in a laminate.
Mat	A randomly distributed felt of glass fibers used in reinforced plastics.
Moisture Resistance	The ability of a material to resist absorption from the air or when immersed in water.
Nylon	The generic name for synthetic fiber-forming polyamides.
Organic	Designating or composed of matter originating in plant or animal life or composed of chemicals of hydrocarbon origin either natural or synthetic.
Oscillatory Surge	A surge which includes both positive and negative polarity values.
Over-potential	A voltage above the normal operating voltage of a device or circuit.
Partial Discharge	A partial discharge is an electric discharge that only partially bridges the insulation system between conductors when the voltage stress exceeds a critical value. These partial discharges may, or may not occur adjacent to a conductor. Partial discharge is often referred to as "corona" but the term "corona" is preferably reserved for localized -discharges in cases around a conductor, bare or insulated, remote from any other solid insulation.
Partial Discharge Pulse	A partial discharge pulse is a voltage or current pulse which occurs at some designated location in the test circuit as a result of a partial discharge.

Partial Discharge Pulse Charge	The quantity of charge supplied to the test specimen's terminals from the applied voltage source after a partial discharge pulse has occurred. The pulse charge is often referred to as the apparent charge or terminal charge. The pulse charge is related but not necessarily equal to the quantity of charge flowing in the localized discharge.
Partial Discharge Pulse Energy	The partial discharge pulse energy is the energy dissipated during one individual partial discharge.
Partial Discharge Pulse Repetition Rate	The partial discharge pulse repetition rate is the number of partial discharge pulses of specified magnitude per unit time.
Partial Discharge Pulse Voltage	The peak value of the voltage pulse which. if inserted in the test circuit at a terminal of the test specimen, would produce a response in the circuit equivalent to that resulting from a partial discharge pulse within the specimen. The pulse voltage is also referred to as the terminal corona pulse voltage.
Particulate *(space particulate debris)*	The sources of spacecraft particulate debris are, earth, spacecraft, and space environments. Earth particulate is mostly dust, sand, and the rocket exhaust. Sources are materials spalled by cosmic dust impacts on materials and the solar array, outgassing products, and slip rings. Space environment are the residues that form the space plasma, cosmic dust of masses less than one gram, micrometeoroids, and meteoroids.
Permittivity	The dielectric constant multiplied by the permittivity of empty space, where the permittivity of empty space, ε_0, is a constant appearing in Coulomb's Law.
Phenolic Resin	A synthetic resin produced by the condensation of phenol with formaldehyde.
Plasma	A gaseous body of ions and electrons of sufficiently low density that considerable charge separation is possible. Because of the mobility of charge, a plasma is normally neutral and free of electric field in its interior, just like a metallic conductor.
Plastic	High polymeric substances, including both natural and synthetic products, but excluding the rubbers, that are capable of flowing under heat and pressure at one time or another.
Polyamide	A polymer in which the structural units arc linked by amide or thioamide groupings

Polycarbonate Resins	Polymers derived from the direct reaction between aromatic and aliphatic dihydroxy compounds with phosgene or by the ester exchange-reaction with appropriate phosgene derived precursors.
Polyester	A resin formed by the reaction between a dibasic acid and a dihydroxy alcohol.
Polyethylene	A thermoplastic material composed of polymers of ethylene.
Polyisobutylene	The polymerization product of isobutylene, also called butyl rubber.
Polymer	A compound formed by polymerization which results in the chemical union of monomers or the continued reaction between lower molecular weight polymers.
Polymerize	To unite chemically two or more monomers or polymers of the same kind to form a molecule with higher molecular weight.
Polymethyl Methacrylate	A transparent thermoplastic composed of polymers of methyl methacrylate.
Polypropylene	A plastic made by the polymerization of high-purity propylene gas in the presence of an organometallic catalyst at relatively low -pressures and temperatures.
Polystyrene	A thermoplastic produced by the polymerization of styrene (vinyl benzene).
Polyvinyl Acetate	A thermoplastic material composed of polymers of vinyl acetate.
Polyvinyl Butyral	A thermoplastic material derived from butyraldehyde.
Polyvinyl Chloride (PVC)	A thermoplastic material composed of polymers of vinyl chloride.
Polyvinyl Chloride Acetate	A thermoplastic material composed of copolymers of vinyl chloride and vinyl acetate.
Polyvinylidene Chloride	A thermoplastic material composed of polymers of vinylidene chloride (1.1-dichloroethylene).
Potential	The work per unit charge required to bring any charge to the point from an infinite distance.
Potting	Similar to encapsulating except that steps are taken to insure complete penetration of all voids in the object before the resin polymerizes.

Power The time rate at which work is done. Power is obtained in watts if work is expressed in joules and time is in seconds.

Pressure Force per unit area. Absolute pressure is measured with respect to zero pressure. Gauge pressure is measured with respect to atmospheric pressure.

Proton An elementary particle that is the positively charged constituent of ordinary matter and, together with the neutron, is a building stone of all atomic nuclei.

Pulse A wave which departs from a first nominal state attains a second nominal state, and ultimately returns to the first nominal state.

Relative Humidity Ratio of the quantity of water vapor present in the air to the quantity which would saturate it at any given temperature.

Resin An organic substance of natural or synthetic origin characterized by being polymeric in structure and predominantly amorphous. Most resins, though not all, are of high molecular weight and consist of long chain or network molecular structure. Usually resins are more soluble in their lower molecular weight forms.

Resistance Property of a conductor that determines the current produced by a given difference of potential. The ohm is the practical unit of resistance.

Resistivity The ability of a material to resist passage of electrical current either through its bulk or on a surface. The unit of volume resistivity is the ohm-cm.

Schering Bridge A four-arm alternating-current bridge used to measure capacitance and dissipation factor; bridge balance is independent of frequency.

Semiconductor A solid crystalline material whose electrical conductivity is intermediate between that of insulators and conductors, and is usually applied-field and temperature-dependent.

Shelf Life Length of time under specified conditions that a material retains its usability.

Silicone Polymeric materials in which the recurring chemical group contains silicon and oxygen atoms as links in the main molecular chain.

Sparkover (spark) A short-duration electric discharge due to a sudden breakdown of air of some other dielectric material separating two terminals, accompanied by a momentary flash of light. Also known as electric spark; spark discharge; sparkover..

Storage Life	The period of time during which a liquid resin or adhesive can be stored and remain suitable for use. Also called Shelf Life.
Surface Creepage Voltage	See Creepage.
Surface Flashover	See Flashover.
Surface Leakage	The passage of current over the boundary surface of an insulator as distinguished from passage through its volume.
Surface Resistivity	The resistance of a material between two opposite sides of a unit square of its surface. Surface resistivity may vary widely with the conditions of measurement.
Surge	A transient variation in the current and/or potential at a point in the circuit.
Tear Strength	Force required to initiate or continue a tear in a material under specified conditions.
Tensile Strength	Maximum stress a material subjected to a stretching load can withstand without tearing. Also known as hot strength.
Thermal Conductivity	Ability of a material to transport thermal energy.
Thermal Endurance	The time at a selected temperature for an insulating material or system of materials to deteriorate to some predetermined level of electrical, mechanical, or chemical performance under prescribed conditions of test.
Thermoplastic	A plastic that can be readily softened and resoftened by heating without changing its inherent properties.
Tracking	Scintillation of the surface of an insulator. May produce enough heat to leave a degraded track of carbon.
Tracking Resistance	See arc resistance.
Transient	That part of the change in a variable that disappears during transition from one steady state operating condition to another.
Urea-Formaldehyde Resin	A synthetic resin formed by the reaction of urea with formaldehyde. An amino resin.

Urethane	A synthetic resin formed by the reaction of a isocyanate resin (nitrogen, carbon, and oxygen radical) with an alcohol.
Vinyl Resin	A synthetic resin formed by the polymerization of compounds containing the group CH2 a CH-.
Void	A small enclosed cavity within an insulation system. It may be centrally located or be next to an electrode surface.
Voltage	The term most often used in place of electromotive force, potential difference, or voltage drop, to designate electric pressure that exists between two points and is capable of producing a flow of current when a closed circuit is connected between the two points.
Volume Resistivity (Specific Insulation Resistance)	The electrical resistance between opposite faces of a 1-cm cube of an insulating material, commonly expressed in ohm-centimeters. The recommended test is ASTM D257-61.
Wire	A metallic conductor of round, square, or rectangular cross-section, which may be either bare or insulated.
Working Life	The period of time during which a liquid resin or adhesive after mixing with catalyst solvent, or other compounding ingredients, remains usable.

This is the last page