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MILITARY HANDBOOK

NASA PARTS APPLICATION HANDBOOK

(VOLUME 5 OF 5)
CONNECTORS, PROTECTIVE DEVICES,
SWITCHES, RELAYS, WIRE, CABLE



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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, D.C. 20546

NASA Parts Application Handbook

1. This handbook is approved for use by all elements of the National Aeronautics and Space Administration and is available for use by all departments and agencies of the Department of Defense.
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FOREWORD

This handbook provides a technological baseline for parts used throughout NASA programs. The information included will improve the utilization of the NASA Standard Electrical, Electronic, and Electromechanical (EEE) Parts List (MIL-STD-975) and provide technical information to improve the selection of parts and their application, and failure analysis on all NASA projects. This handbook consists of five volumes and includes information on all parts presently included in MIL-STD-975.

This handbook (Revision B) succeeds the initial release. Revision A was not released. The content in Revision B has been extensively changed from that in the initial release.

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13.1 CONNECTORS, GENERAL

13. CONNECTORS, POWER

13.1 General.

13.1.1 Introduction. This section contains general information for multipin power connectors and contacts identified in MIL-STD-975 NASA Standard Electrical, Electronic, and Electromechanical (EEE) Parts Lists for use in Grade 1 and Grade 2 applications. The connectors are classified as rack and panel, circular, and printed circuit types. Within each type are categories of contact size, operating temperature range, environment-resistance capability, contact density, and coupling mechanisms.

The information in this section is intended to help the equipment designers select electrical connectors and associated hardware from those devices contained in MIL-STD-975. The information pertaining to specific connector types is contained in its appropriate section. The most important decision a user must make is which of the numerous types of connectors and associated hardware will be the most suitable for use in the particular equipment he is designing. Proper selection, in its broadest sense, is the first step in building reliable equipment. To effectively and properly select the connectors and associated hardware to be used, the user must know as much as possible about the types from which he can choose. He should know the advantages and disadvantages, the behavior under various environmental conditions, the construction, the effect upon the circuits, the effect of the circuit upon the connector, as well as what causes connectors to fail.

13.1.1.1 Applicable military specifications.

MIL-C-5015	Connector, Electrical, Circular Threaded, General Specification for
MIL-C-22992	Connector, Plugs and Receptacles, Electrical, Waterproof, Quick Disconnect, Heavy Duty Type, General Specification for
MIL-C-24308	Connectors, Electrical, Rectangular, Miniature Polarized Shell, Rack and Panel
MIL-C-26482	Connectors, Electrical, (Circular, Miniature, Quick Disconnect, Environmental Resisting) Receptacles and Plugs, General Specification for
MIL-C-38999	Connector, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet Threaded, and Breech Coupling), Environmental Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for

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13.1 CONNECTORS, GENERAL

MIL-C-39029	Contact, Electrical Connector, General Specification for
MIL-C-55302	Connector, Printed Circuit Subassembly and Accessories

13.1.1.2 Applicable NASA specifications.

40M38277	Connectors, Electrical, Circular, Miniature High Density Environment Resisting, Specification for
40M38298	Connectors, Electrical Special, Miniature Circular, Environment Resisting
40M39569	Connectors, Electrical, Miniature Circular, Environment Resisting 1200 °C, Specification for
GSFC S-311-P-4	Connectors (and Contacts), Electri- cal, Rectangular, for Space Flight Use, General Specification for
GSFC S-311-P-10	Connectors, Subminiature, Electri- cal and Coaxial Contact, for Space Flight Use
ASTM-E-595	Standard test method for total mass loss and collected volatile condensable materials from outgassing in a vacuum environment.

13.1.2 General definitions. Terms which are commonly used in electrical connector engineering practice and generally accepted by the electrical and electronic industries are as follows:

Adapter. An intermediate device to provide for attaching special accessories or to provide special mounting means.

Accessories. Mechanical devices, such as cable clamps, that are added to connectors.

Ambient temperature. The temperature of the environment, usually air, surrounding a connector.

Arc resistance. The tendency of insulating material to resist breakdown or passage of current on the surface between contacts and between contacts and ground.

Back-mounted. A connector mounted from the inside of a panel or box with its mounting flange inside the equipment.

13.1 CONNECTORS, GENERAL

Barrel, crimp. The section of the terminal, splice, or contact that accommodates the stripped conductor.

Barrel chamfer. The bevel at the end of the conductor barrel which facilitates entry of the stripped conductor.

Basis metal. Metal from which the connector components are made and on which one or more metals or coatings may be deposited.

Bayonet coupling, rotary. A quick coupling device for mating connectors utilizing pins on one connector and ramps on the mating connector. Mating and unmating is accomplished by rotating the coupling ring.

Body, connector. The main portion of a connector to which contacts and other components are attached. This term is not used with connectors incorporating nonintegral shells in their construction.

Bonded assembly, electrical. An assembly whose supporting frame and metallic noncircuit elements are connected so as to be electrically shorted together.

Boot. A form placed around the wire terminations of a multiple contact connector as a protective housing or as a container for potting compound.

Braid. 1. A flexible conductor made of a woven or braided assembly of fine wires. 2. A fibrous or metallic group of filaments interwoven in cylindrical form to form a protective covering over one or more wires.

Bused. The joining of two or more circuits.

Cable clamp. A mechanical clamp attached to the cable side of the connector to support the cable or wire bundle, provide strain relief, and absorb vibration and shock, that would otherwise be transmitted by the cable to the contact/wire connection.

Cable clamp adapter. A mechanical adapter that attaches to the rear of a connector to allow the attachment of a cable clamp.

Cable sealing clamp. A device consisting of a gland nut and sealing member designed to seal around a single jacket cable.

Cable shielding clamp. A device consisting of a sealing member and cable support designed to terminate the screen (shield) of an electrical cable.

Circumferential crimp. The type of crimp in which the crimping die completely surrounds a barrel, resulting in symmetrical indentations in the barrel.

Closed entry. A contact or contact cavity design in the insert or body of the connector which limits the size or position of the mating contact or printed circuit board to a predetermined dimension.

13.1 CONNECTORS, GENERAL

Configuration control. The discipline providing for uniformity of materials, processes, geometry, and performance in manufactured items.

Connector, electrical. A device, either a plug or a receptacle, used to terminate or connect the conductors of individual wires or cables and which provides a means to continue the conductors to a mating connector or printed circuit board.

Connector set, electrical. Two or more separate connectors (plug connector and receptacle connector) which are designed to be mated together. The set may include mixed connectors mated together such as one connector plug and one dummy connector receptacle or one connector receptacle and one dummy electrical plug.

Connector classes. Categories based on the performance capabilities of the connectors. Classification categories include environment-resistant, firewall, and hermetically sealed connectors.

Contact. The conductive element in a connector which makes physical contact with another contact on the mating connector for the purpose of transferring electrical energy.

Contact area. The area in contact between two conductors, two contacts, or a conductor and a contact permitting the flow of electrical current.

Contact arrangement. The number, spacing, and arrangement of contacts in a connector.

Contact, crimp. A contact whose conductor barrel is a hollow cylinder that accepts the conductor. After a bared conductor is inserted, a crimping tool is applied to swage or form the contact metal firmly against the conductor. An excellent mechanical and electrical joint results. A crimp contact is often referred to as a solderless contact.

Contact engaging and separating force. The force needed to either engage or separate mating contacts.

Contact, female. A contact of such design that the mating contact is inserted therein; this is similar in function to a socket contact.

Contact, fixed. A contact which is permanently included in the insert material. It is mechanically locked, bonded, or embedded in the insert.

Contact float. The overall side play and angular displacement of contacts within the insert cavity.

Contact, insertable/removable. A contact that can be mechanically joined to, or removed from, an insert. Usually, special tools are required to lock the contact in place or remove it for repair or replacement.

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13.1 CONNECTORS, GENERAL

Contact, male. A contact of such design as to make contact by insertion into a mating contact. This is similar in function to a pin contact.

Contact, open entry. A socket contact whose engaging end is split and therefore vulnerable to distortion or damage from test probes or other wedging devices.

Contact, pin. A male type contact designed to slip inside the mating female contact member.

Contact resistance. Electrical resistance of a pair of engaged contacts. Resistance may be measured in ohms or millivolt drop at a specified current through the engaged contacts.

Contact retainer. A device either on the contact or in the insert that retains the contact in an insert or body.

Contact retention. The axial load in either direction that a contact can withstand without being dislodged from its normal position within an insert or connector body.

Contact shoulder. The flanged portion of the contact that limits its depth into the insert.

Contact size. An assigned number denoting the size of the contact engaging end.

Contact, socket. A female-type contact that is designed to accept the mating pin contact member.

Contact, solder. A contact having a cup, hollow cylinder, eyelet, or hook to accept a conductor and retain the applied solder.

Contact wipe. The distance of travel (physical engagement) made by one contact with another during its engagement or separation or during mating or unmating of the connector halves.

Corona. A luminous discharge of electricity due to ionization of the air appearing on the surface of a conductor when the potential gradient exceeds a certain value.

Coupling ring. That portion of a plug which aids in the mating or unmating of a plug and receptacle and holds the plug to the receptacle.

Cover, electrical connector. An item which is specially designed to cover the mating end of a connector for mechanical and environmental protection.

Creep distance. The shortest distance on the surface of an insulator separating two electrically conductive surfaces.

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Creepage path. The path across the surface of dielectric between two conductors. Lengthening the creepage path reduces the possibility of arc damage or tracking.

Crimp. The physical compression (deformation) of a contact barrel around a conductor to make an electrical and mechanical connection.

Crimping. A pressure method of mechanically securing a terminal, splice, or contact to a conductor.

Crimping die. The portion of the crimping tool that shapes the crimp.

Crimping tool. The mechanism used for crimping.

Current-carrying capacity. The current a conductor of given size and length is capable of carrying safely without exceeding its temperature limitations.

Cutout, connector. The hole, usually round or rectangular, cut in a metal panel for mounting a connector. The cutout may include holes for mounting screws or bolts.

Depth of crimp. The distance the indenter penetrates radially into the crimp barrel.

Dielectric. A material having electric insulating properties.

Dummy connector assembly, electrical. Two or more electrical dummy connectors having a common mounting or mounted on each other, each one capable of being independently replaced. Excludes items which are furnished as mated pairs or sets.

Dummy connector, receptacle. A connector receptacle which does not have provisions for attaching conductors. It is generally used for stowage of a cable assembly connector plug.

Environmentally sealed. A device that is provided with gaskets, seals, grommets, potting, or other means to keep out moisture, dirt, air, or dust which might reduce its performance. Does not include nonphysical environments such as rf and radiation.

Extraction tool. A device used for removing removable contacts from a connector.

Ferrule. A short tube used to make solderless connections to shielded or coaxial cables. Also used in connectors to reduce transmission of torque to the grommet.

Flange, connector. A projection extending from or around the periphery of a connector with provisions to permit mounting the connector to a panel.

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13.1 CONNECTORS, GENERAL

Flux. A material used to promote fusion or joining of metals in soldering, brazing, or welding.

Follower. A sleeve used to compress the grommet, thus tightening the seal around the conductors entering the termination assembly.

Front mounted. A connector mounted on the outside of a panel or box with its mounting flange outside the equipment.

Grid spaced. The arrangement of contacts in a multiple contact termination assembly by spacing in a geometric pattern.

Grommet, connector. An elastomeric seal used on the cable side of a connector to seal the connector against moisture, dirt, and air.

Grope free. A situation in which a connector coupling system can easily be mated and locked, usually with one hand. A coupling ring that is held in the proper position to start the mating cycle while uncoupled.

Ground, electrical. A point of common potential in an electric circuit used for common connections and reference voltage.

Guide pin. A pin or rod extending beyond the mating faces of a connector designed to guide the mating or unmating of the connector to ensure proper engagement or disengagement of the contacts.

Housing, connector, electrical. The connector less the insert, but with the insert-retaining and positioning hardware required by standard construction.

Impedance. The total opposition (resistance and reactance) a circuit offers to the flow of electric current. It is measured in ohms and its reciprocal is admittance, usually expressed in siemens.

Insert arrangement. The number, spacing, and arrangement of contacts in a termination assembly.

Insert, closed entry. An insert having openings that restrict the entry of devices larger than the specified contact.

Insert, electrical connector. An insulating element with or without contacts that is designed to position and support contacts in a connector.

Insertion tool. A device used to insert contacts into a connector and to insert taper pins into taper pin receptacles.

Inspection hole. A hole placed at one end of a crimp barrel to permit visual inspection to see that the conductor has been inserted to the proper depth in the barrel prior to crimping.

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Insulation support. The portion of a barrel that supports but does not compress the conductor insulation.

Interface. The two surfaces on the contact side of mating connectors that face each other when mated.

Interfacial gap. Any gap between the faces of mated inserts.

Interfacial seal. A sealing of mated connectors over the whole area of the interface to provide sealing around each contact.

Jacket. The outermost layer of insulating material of a cable or wire.

Jackscrew (screwlock). A screw attached to one half of a two-piece multiple contact connector used to draw and hold both halves together. A jackscrew may also be used to separate two connector halves.

Key. A short pin or other projection which slides in a mating slot, hole, groove, or keyway to guide parts being mated. Keys are generally used in circular connectors to obtain polarization.

Keyway. A slot or groove in which a key slides.

Mold, potting, electrical connector. A device, consisting of one or more pieces, designed to be used as a hollow form into which potting compound is injected and allowed to cure (or set) to seal the back of an electrical connector. The potting may eliminate the need for a backshell of the connector. The form may or may not be removable after the potting compound cures.

Nest. The portion of a crimping die which supports the barrel during crimping.

Operating temperature. The maximum temperature resistance capabilities of a connector in continuous service.

Panel. The side or front of a piece of equipment, usually metal, on which connectors are mounted.

Pin contact. A contact having an engagement end that enters the socket contact.

Plating. The deposition of a thin coating of metal on metallic components to improve conductivity, provide for easy soldering, or prevent corrosion.

Plug, connector. An electrical fitting with pin, socket, or pin and socket contacts, constructed to be affixed to the end of a cable, conduit, coaxial line, cord, or wire for convenience in joining with another electrical connector and not designed to be mounted on a bulkhead, chassis, or panel.

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13.1 CONNECTORS, GENERAL

Polarization. A coded arrangement of keys, keyways, and insert positions which prohibits the mating of mismatched plugs and receptacles. Polarization allows connectors of the same size to be lined up side by side with no danger of making the wrong connection. The polarization of rectangular connectors is usually accomplished by the design of the shell or the mating hardware so that mating is possible in only one orientation.

Polarizing pin, key, or keyway. A device incorporated in a connector to accomplish polarization.

Potting. The permanent sealing of the cable end of a connector with a compound or material to exclude moisture and to provide a strain relief.

Pretinned. Solder applied to either or both the contact and conductor prior to soldering.

Pull-out force. The force necessary to separate a conductor from a contact or terminal, or a contact from a connector, by exerting a tensile pull.

Quick disconnect. A type of connector or splice which permits relatively rapid locking and unlocking of mating parts.

Rack-and-panel. A type of connector that is attached to a panel or side of equipment so that the connector is engaged when these two members are brought together.

Radio frequency (rf). The frequency spectrum from 15 KHz to 10,000 MHz.

Radio frequency interference (rfi). Electromagnetic radiation in the radio frequency spectrum from 15 KHz to 10,000 MHz. The best shielding materials against rfi are copper and aluminum alloys. The term EMI should not be used in place of rfi because shielding materials for the entire electromagnetic frequency spectrum are not available.

Range, wire. The sizes of conductors accommodated by a particular crimp barrel. Also the diameters of wires accommodated by a sealing grommet.

Receptacle, connector. An electrical fitting with contacts constructed to be electrically connected to a cable, coaxial line, cord, or wire to join with another electrical connector, and designed to be mounted on a bulkhead, wall, chassis, or panel.

Scoop-proof. The feature that prevents connector pins from bending during mating or unmating.

Sealing plug. A plug which is inserted to fill an unoccupied contact aperture in a termination assembly. Its function is to seal all unoccupied apertures in the assembly, especially in environmental connectors or junctions.

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13.1 CONNECTORS, GENERAL

Sealing plug. A plug which is inserted to fill an unoccupied contact aperture in a termination assembly. Its function is to seal all unoccupied apertures in the assembly, especially in environmental connectors or junctions.

Service life. A period of time over which a device is expected to perform in accordance with its specified requirements.

Service rating. The maximum voltage or current which a connector is designed to carry continuously.

Shell, electrical connector. The outside case of a connector into which the dielectric material and contacts are assembled.

Shield, electrical connector. An item especially designed to be placed around that portion of a connector which contains the facilities for attaching wires or cables. It is used for shielding against electrical interference or mechanical injury and usually has provisions for passage of the wire or cable.

Socket contact. A contact having an engagement end that will accept entry of a pin contact.

Solder cup. The end of a terminal or contact in which the conductor is inserted prior to being soldered.

Solder eye. A solder type contact provided with a hole at its end through which a wire can be inserted prior to being soldered.

Solderless connection. The joining of two metals by pressure means without the use of solder, braze, or any method requiring heat.

Solderless wrap. A technique of connecting stripped wire to a terminal post containing a series of sharp edges by winding the wire around the terminal.

Strip. To remove insulation from a conductor.

Threaded coupling. A means of coupling mating connectors by engaging threads in a coupling ring with threads on a receptacle shell.

Tubular adapter. An accessory attached to the rear of a termination assembly, usually metallic, used to extend the shell far enough to support a sealing gland or to give mechanical support for a cable or conductor harness.

Umbilical connector. A connector used to connect cables to a rocket or missile prior to launching and which is unmated from the missile at the time of launching.

Wiping action (see contact wipe). The action of two electrical contacts which come in contact by sliding against each other.

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13.1 CONNECTORS, GENERAL

Work curve. A graph which plots the pull out force, indent force, and relative conductivity of a crimp joint as a function of various depths of crimping.

Working voltage. The maximum voltage at which a connector is rated to operate.

13.1.3 General device characteristics. A connector must be capable of mating and unmating in its intended application, provide electrical continuity (when mated) adequate for the functions of the circuitry involved, and maintain adequate insulation between the conductors. These requirements are fundamental; however, there are many other factors to be considered that influence the selection of connectors. Some of these factors are:

- a. Limitation on size, weight, and cost
- b. Current carrying capacity and voltage withstanding ability
- c. Ease of installation and repair
- d. Ease of operation (mating and unmating).

Connectors should be used within the design limitations stated in the manufacturer's ratings and in the class of service for which they are intended. However, the following special design considerations should always be considered:

- a. What are the current and voltage requirements?
- b. How many signal circuits?
- c. How many power circuits?
- d. What number and type of conductors?
- e. Shielded, rf, coaxial?
- f. How many of each size conductor?
- g. Type and physical characteristics of wire?

13.1.3.1 Human engineering. The human engineering aspects of the connector application must be considered by the equipment designs. For example, if a coupling ring must be unscrewed by hand, room must be allowed around the connector so that a hand can do this. Can it be reached and manipulated from where a person must stand? Can maintenance and repair operations be carried out with reasonable convenience?

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13.1 CONNECTORS, GENERAL

13.1.3.2 Safety. The connector application should be planned so that the recessed female contacts are used on the "hot" or power side of the circuit. This is done so that there is no danger of shock when handling or touching the connector. The mating connector having exposed male pins should be used on the "dead" side of the connection. The exposed pins should be enclosed in the connector housing to prevent damage.

When more than one connector of the same type is used on the same panel, connectors with alternate mating keyways should be used to prevent mismatching.

13.1.3.3 Alignment. Many connectors are designed with a certain amount of float in the contacts or in the housing. This permits the contacts or housing to align themselves in the proper position during mating. It is important that the mounting of the connector and the dress of the wire bundle behind the connector be arranged to allow wire slack so as not to restrict the float. If the rear surface of the connector is to be potted after wiring, a resilient potting material must be used. It is desirable to have the connector mated with its mating half or an equivalent fixture during potting so that the contacts are in proper alignment as the potting material sets up. Care in cable dressing is especially important with connectors having removable contacts. To maintain proper contact alignment and prevent possible damage to the contact, the cable should not make a sharp right angle bend at the end of the connector.

13.1.3.4 Number of circuits carried. When a large number of leads are to be accommodated, several separate connectors may prove more satisfactory than a single connector. Spare contacts in a quantity of 10 percent of the total contacts required should be provided. In addition to the difficulties in coupling a large connector, consideration should be given to the total current the connector must carry and the temperature rise in the connector due to contact resistance. Contact resistance can be expected to increase approximately 75 percent after exposure to a salt atmosphere.

13.1.3.5 Insulation material. The insulation material separating the connector contacts requires prime consideration. A wide variety of insulators have been developed. Each has a long list of electrical and mechanical properties, any one of which might be the dominant characteristic for the application. Some of the common materials used are listed in Table I.

13.1.4 General parameter information. Connector selection must be based on electrical, mechanical, and environment-resistant qualities as required by the application (see Table II).

The principal sources of information on performance characteristics are the military specifications, data from connector manufacturers, and the user's history of previous performance.

13.1 CONNECTORS, GENERAL

TABLE I. Properties of insulating materials

Parameter	Neoprene	Silicone	Diallyl Phthalate	Epoxy	Phenolic
Dielectric strength (volts/mil)	300	500	350	350	350
Temperature resistance (°C) (1000 hours)	120	250	175	230	200
Tensile strength (psi)	1,200	4,000	6,000	11,000	10,000
Low temperature properties	Poor	Excellent	--	--	--
Oil resistance	Good	Excellent	--	--	--
Compression set	Fair	Excellent	--	--	--
Outgassing at 55 °C	High	Low	Low	Very low	Low
Insulation resistance	Fair-Good	Excellent	Excellent	Good	Good

TABLE II. Connector specification considerations

Performance Classification	Parameters to Consider	
Electrical	Voltage Current Insulation resistance Contact resistance	Grounding rf characteristics Number of contacts
Mechanical	Coupling system Connector mating alignment Contact retention	Wire terminations Seals Interfaces
Environmental	Temperature Pressure differential Vibration Shock Thermal cycling	Acceleration Moisture Sand and dust Fluids

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13.1 CONNECTORS, GENERAL

Two areas where the application of specification information vitally affects expected reliability are:

- a. Exceeding any one specified rating
- b. Applying more than one published performance characteristic at maximum rating.

When either of the two conditions noted above must be encountered, the selection of the connector used should only be made after manufacturers and users have been contacted to determine best performance trade-off.

13.1.5 General guides and charts. General characteristics of power connectors are given in Table III.

TABLE III. General characteristics of power connectors

Connector	Contact Size	Contact Termination	Coupling Type	Temperature Range	Moisture Resistant
MIL-C-5015 (Power)	#0 to #16	Solder and crimp	Threaded coupling	-55 to +125 °C	Yes
MIL-C-22992 (Heavy duty)	#0 to #16	Solder	Threaded coupling	-55 to +125 °C	Yes
MIL-C-24308 (Rack and Panel)	#20,22	Solder and crimp	Jackscrews	-55 to +125 °C	No
MIL-C-26482 (Circular)	#12,16,20	Solder and crimp	Bayonet	-55 to +200 °C	Yes
MIL-C-38999 (Miniature)	#12 to #22	Solder and crimp	Bayonet	-65 to +150 °C	Yes
MIL-C-55302 (Printed Circuit)	#22	Solder and crimp	Jackscrews	-65 to +125 °C	No

13.1.6 General reliability considerations. The reliability of typical connectors compares favorably with that of other components used in electrical and electronic equipment. Factors that tend to degrade connector reliability include the added complexity of new multicontact designs with their multiplicity of parts, the variety of contact termination methods, and the more extreme environmental requirements imposed by complex modern systems. Failure rate prediction data for electrical connectors is presented in MIL-HDBK-217.

13.1 CONNECTORS, GENERAL

13.1.6.1 Mechanical effects. Achieving good electrical contact in a connector is a function of surface films (oxides and sulphides), surface roughness, contact area, plastic deformation of the contacting materials, and load applied.

Because even the best machined, polished, and coated surfaces look rough and uneven when viewed microscopically, the common concept of a flat, smooth contact is grossly oversimplified. In reality, the connector interface is basically an insulating barrier with a few widely scattered points of microscopic contact. The performance of the connector is dependent upon the chemical, thermal, and mechanical behavior at these contact points.

13.1.6.2 Electrical effects. Current flow between mating metals is constricted at the interface to the small points on the surfaces which are in electrical contact. This flow pattern causes differences of potential to exist along the contact interface, and causes higher current flow at points of lower resistance. As a result, contact resistance and capacitance are introduced into the circuit, and certain chemical effects evolve (see following paragraph on chemical effects).

13.1.6.3 Thermal effects. The total contact resistance of a pin and socket contact pair is a parallel combination of many higher resistance-areas of point contact. The effect is that of a series of localized hot spots, all contributing to an average integrated temperature rise at the interface. When high currents are conducted through many contact pairs, the cumulative heat rise in the connector can be appreciable. This heat rise above the ambient or body temperature is a deciding factor in connector reliability.

Excessive temperature can cause failure of connectors by breakdown of insulation or by breakdown in the conductivity of the conductors. Either malfunction can be partial or complete.

A typical breakdown caused by excessive temperature occurs progressively as follows: as operating temperature increases, the insulation tends to become more conductive, and simultaneously, the resistance of the conductors increases. Higher resistance causes the temperature of the conductor and of its insulation to rise further. This pyramiding effect can raise the temperature of conductors and connector contacts beyond their maximum operating temperatures with resultant damage occurring to the contacts and conductive platings. Complete breakdown will occur if the operating temperature reaches the point where the conductor melts, breaking electrical conductivity; or where the insulation fails, causing a short.

Maximum operating temperatures are the sum of the ambient temperature and the conductor temperature rise caused by the passage of current. A maximum conductor operating temperature of 125 °C, for example, is based on an ambient temperature of 100 °C, plus a rise of 25 °C due to the conductor carrying current.

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13.1 CONNECTORS, GENERAL

Extremely low temperatures introduce the same kind of problems to the design of the interconnection system as to any other portion of a system. Metals and non-metals tend to become brittle and shrink at different rates. The relative importance of each characteristic depends on the application. Most high-performance connectors will operate at temperatures as low as -55°C . Operation at lower temperatures may require special materials.

Temperatures below normal ambient are not usually the cause of conductivity problems in interconnection systems (more current can be carried by a given conductor at lower temperatures). However, extremely low ambient temperatures do produce mechanical failures, which occur most often in the nonmetallic portions of connectors, wires, and cables. The coefficients of expansion of most polymers and elastomers are so different from those of the metals used in structural members that they will contract enough at extremely low temperatures to open seals. An open seal will not cause a malfunction unless contaminants can enter through the opening. If a seal opens after the temperature of a connector falls below the freezing point of the contaminants present, and then seals itself before the melting point of the contaminants is reached, foreign matter will never enter. If, however a connector seal will open at a temperature where all liquid or gaseous contaminants have not been frozen, a more suitable type of material or mechanical arrangement is required.

13.1.6.4 Chemical effects. Most connector failures resulting from chemical effects are induced by the growth of films at points of contact. These films can cause increased contact resistance or an open circuit. Contact resistance gives rise, as explained above, to interfaces at higher temperatures than the surroundings, thus increasing the chemical activity.

Normally, the purity of metals in contact is not considered a reliability problem. However, ions in impurities or contamination in the surface pores will migrate to the points of highest potential, which are frequently the localized hotspots. Ions interfacing with electrons and other constituents at the points of high chemical activity generate films, which are usually nonconducting. There is also a continuous supply of material for the growth of insulating films from environments where there are corrosive elements such as hydrogen sulfide, water vapor, oxygen, ozone, hydrocarbons, and various dusts.

13.1.6.5 Cycling effects. Repeated mating and unmating of connectors exposes the contacts to a fresh supply of local corrosive contaminants during each mating cycle. There is also the problem of physical wear on the connecting interfaces in this type of operation. The result is increased interface resistance, temperature, and degradation of the connection.

13.1.6.6 Materials. Materials capable of emitting vacuum condensable, noxious or toxic gases when tested in accordance with ASTM E 595 shall not be used. Materials with a total mass (TML) of less than 1.0% and collected volatile condensable materials (CVCM) less than 0.10% are generally considered acceptable for NASA use. The outgassing requirements are not controlled in MIL-STD-975. Consult the project parts engineer for recommendations.

**13.2 CONNECTORS, CIRCULAR,
MIL-C-26482**

13.2 Circular, MIL-C-26482.

13.2.1 Introduction. This specification covers environment-resisting, bayonet coupling, and circular connectors with solder or rear release removable crimp contacts.

Receptacles are available in the following mounting styles: square flange, jam-nut, and solder mount.

Four service classes are available: grommet seal, hermetic seal solder contacts, hermetic seal crimp contacts, and fluid resistant.

Some available accessories are: protective covers, stowage receptacles, strain relief clamps, and rfi backshells.

These connectors meet the requirements of MIL-C-26482, Series 2.

13.2.2 Usual applications. These connectors are intended for use in environment-resisting applications where an operating temperature range of -55 to +175 °C or -55 to +200 °C is experienced. Contacts are available with crimp or solder terminations. Crimp contacts are preferred because they can be replaced individually. Solder contacts are molded in the connector and damage to any one contact requires the replacement of the entire connector. These connectors are moisture sealed and can operate, when mated, in 95 percent relative humidity.

13.2.3 Physical construction. Figures 1 through 4 illustrate various types of circular connectors.

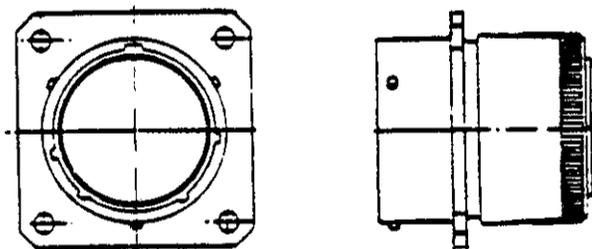


FIGURE 1. Square flange, MIL-C-26482.

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**13.2 CONNECTORS, CIRCULAR,
MIL-C-26482**

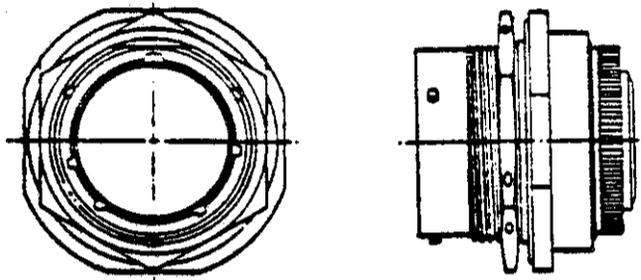


FIGURE 2. Jam-Nut, MIL-C-26482.

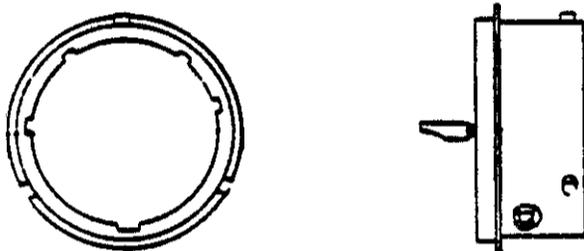


FIGURE 3. Solder mount, MIL-C-26482.

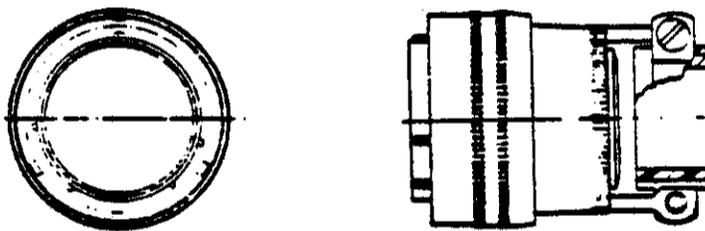


FIGURE 4. Plug, MIL-C-26482.

13.2.3.1 Insert design and construction. Inserts are of voidless construction and are secured to prevent rotation within the shell. The inserts are not removable from the shell and are installed in the position specified on the applicable military standard. A wire sealing grommet is an integral part of the insert assembly. The design will permit the removal and reinsertion of individual crimp contacts using the applicable tools.

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13.2 CONNECTORS, CIRCULAR,
MIL-C-26482

13.2.3.2 Contacts. Solder contacts (Class H) are not removable from the connector. Solder cups are designed so that the connector will not be damaged and no liquid solder will escape during soldering.

Crimp contacts are designed to meet the requirements of MIL-C-39029. Connectors are designed to permit individual insertion and extraction of contacts without removing the insert or sealing members. Insertion and extraction is done from the wire side of the connector and with the aid of tools listed in the applicable military standard.

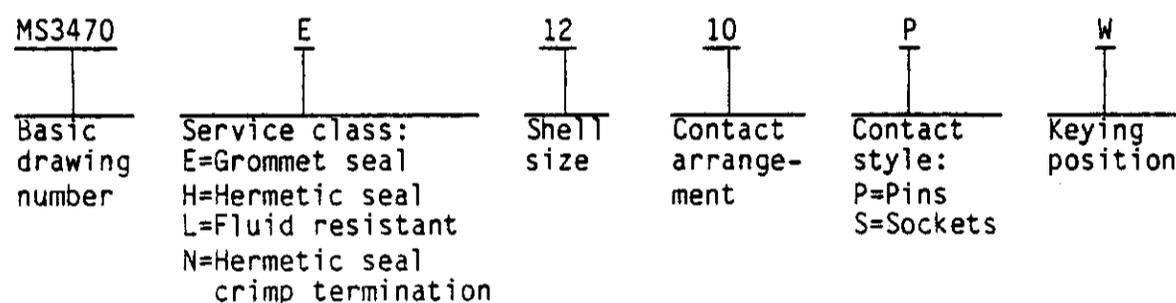
13.2.3.3 Contact spacing. Two service ratings are available. The service ratings differ in the contact center-to-center spacing and the minimum dielectric thickness as specified in MIL-C-26482.

13.2.3.4 Bayonet coupling. Coupling is done by clockwise rotation of the coupling ring; uncoupling is done by counterclockwise rotation. The coupling rings are knurled to provide a gripping surface.

13.2.3.5 Polarization. Polarization is done by matched integral keys and keyways of counter-part connectors. Only connectors with matching keys and keyways will mate. To assure proper contact alignment, keys and keyways are designed to engage before the pin contact enters the socket contact.

13.2.3.6 Interfacial seal. An interfacial seal is provided to minimize air voids between adjacent contacts and between contacts and the shell. This feature improves high-altitude voltage performance. This seal also prevents the entrance of moisture, salt, fog, and fuels when the connector is mated.

13.2.4. Military designation. Qualified connectors are procured by military standards drawings. The following is an example of a complete number for a MIL-C-26482 connector. Basic drawings provide detail information for connectors supplied to MIL-C-26482.



13.2.5 Electrical characteristics.

13.2.5.1 Contact resistance limits. Contact resistance for mated contacts is often expressed as millivolt drop measured across the mated contact pair. The maximum allowable voltage drop is specified in MIL-C-26482 for various combinations of contact size, wire gauge, test current, and service class.

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**13.2 CONNECTORS, CIRCULAR,
MIL-C-26482**

13.2.5.2 Working voltages. Maximum working voltages are specified in MIL-C-26482.

13.2.5.3 Insulation resistance. The insulation resistance of MIL-C-26482 connectors is 5,000 megohms for series 2 connectors when measured as specified in the military specification. Insulation resistance decreases with increasing temperature. Insulation resistance derating curves are presented in MIL-C-26482.

13.2.6 Environmental considerations. There are no unusual environmental considerations for these connectors. MIL-C-26482 connectors are considered to be environment resistant. Performance requirements, including the environmental qualification tests are listed in MIL-C-26482.

13.2.7 Reliability considerations. These connectors have been widely used in military systems for many years, and the design is considered to be mature. Some problems that occasionally arise are contact retention failures, difficulty in intermating connectors supplied from different vendors, and loss of electrical continuity in mated contact pairs.

Contact retention failures are most often due to improper assembly techniques or faulty contact retention systems in the connector. Operator training is usually sufficient to eliminate problems due to improper assembly techniques. Increased attention by the vendor to manufacturing processes and quality control will generally eliminate faults in the contact retention system.

Difficulty in mating connector halves which have been supplied from different vendors is often traced to dimensions which are out of tolerance. This problem can be eliminated with better control over the manufacturing process and increased process and increased emphasis on quality control.

Electrical failures of the contacts are most often caused by contamination, improper heat treatment of the socket springs, or dimensions which are out of tolerance.

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**13.3 CONNECTORS, CIRCULAR, MINIATURE,
HIGH DENSITY, MIL-C-38999**

13.3 Circular, miniature, high density, MIL-C-38999.

13.3.1 Introduction. These connectors are circular, high density, quick-disconnect, environment-resisting connectors. These connectors are classified as follows: Series I - scoop-proof and Series II - low-silhouette. Series I and II connectors are not interchangeable or intermateable.

This specification employs removable crimp contacts, except in the hermetic types, where nonremovable solder type contacts are used. A three-pin bayonet coupling mechanism is employed with these connectors. Receptacle mounting is accomplished three ways: flange mount, jam-nut mount and solder mount. Three types of seals are used: grommet seal, potted seal and hermetic seal. Available accessories include protective covers and caps, potting boots, strain relief clamps, adapters, and stowage receptacles.

13.3.2 Usual applications. These miniature circular connectors are designed for use in environment resisting applications where an operating temperature range of -65 to +200 °C is encountered. These connectors offer high contact density, light weight, and low profile characteristics which are desirable where weight and available space must be considered. Removable crimp contacts are preferred because it is possible to replace any one contact. Solder contacts are glass-sealed molded in the connector, and any damaged contact requires the replacement of the entire connector.

13.3.3 Physical construction.

13.3.3.1 Typical configurations. MIL-C-38999 connectors are available in five configurations: straight plug, box mounting receptacle, wall mounting receptacle, jam-nut mounting receptacle and solder mounting receptacle. Typical configurations are shown in Figures 5 through 9.

13.3.3.2 Polarization. Polarization is accomplished by means of five integral keys and matching keyways on the counterpart connector half. Polarization is accomplished before the initial engagement of the coupling ring is possible. During axial engagement the pins do not touch the sockets or the insert face until polarization has been achieved.

13.3.3.3 Insert design and construction. Inserts are of voidless construction and are secured to prevent rotation within the shell. The inserts are non-removable from the shell, and are positioned in the shell in accordance with the applicable military standard drawing or specification sheet. Individual crimp contacts may be removed or inserted using appropriate military standard contact insertion or withdrawal tools.

13.3.3.4 Contact arrangement. The contact positions are delineated in the applicable military standard drawing specification sheet.

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**13.3 CONNECTORS, CIRCULAR, MINIATURE,
HIGH DENSITY, MIL-C-38999**



FIGURE 5. Straight plug, MIL-C-38999.

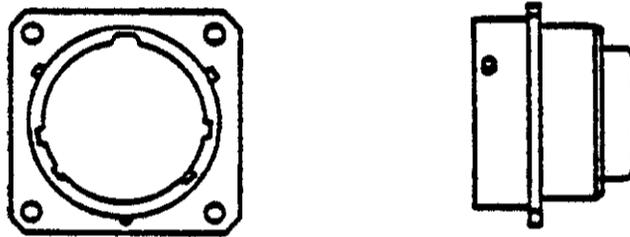


FIGURE 6. Box mounting receptacle, MIL-C-38999.

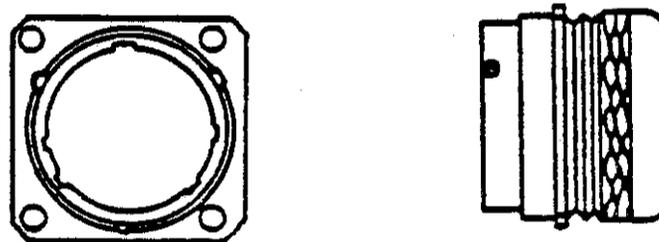


FIGURE 7. Wall mounting receptacle, MIL-C-38999.

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**13.3 CONNECTORS, CIRCULAR, MINIATURE,
HIGH DENSITY, MIL-C-38999**

13.3 Circular, miniature, high density, MIL-C-38999.

13.3.1 Introduction. These connectors are circular, high density, quick-disconnect, environment-resisting connectors. These connectors are classified as follows: Series I - scoop-proof and Series II - low-silhouette. Series I and II connectors are not interchangeable or intermateable.

This specification employs removable crimp contacts, except in the hermetic types, where nonremovable solder type contacts are used. A three-pin bayonet coupling mechanism is employed with these connectors. Receptacle mounting is accomplished three ways: flange mount, jam-nut mount and solder mount. Three types of seals are used: grommet seal, potted seal and hermetic seal. Available accessories include protective covers and caps, potting boots, strain relief clamps, adapters, and stowage receptacles.

13.3.2 Usual applications. These miniature circular connectors are designed for use in environment resisting applications where an operating temperature range of -65 to +200 °C is encountered. These connectors offer high contact density, light weight, and low profile characteristics which are desirable where weight and available space must be considered. Removable crimp contacts are preferred because it is possible to replace any one contact. Solder contacts are glass-sealed molded in the connector, and any damaged contact requires the replacement of the entire connector.

13.3.3 Physical construction.

13.3.3.1 Typical configurations. MIL-C-38999 connectors are available in five configurations: straight plug, box mounting receptacle, wall mounting receptacle, jam-nut mounting receptacle and solder mounting receptacle. Typical configurations are shown in Figures 5 through 9.

13.3.3.2 Polarization. Polarization is accomplished by means of five integral keys and matching keyways on the counterpart connector half. Polarization is accomplished before the initial engagement of the coupling ring is possible. During axial engagement the pins do not touch the sockets or the insert face until polarization has been achieved.

13.3.3.3 Insert design and construction. Inserts are of voidless construction and are secured to prevent rotation within the shell. The inserts are non-removable from the shell, and are positioned in the shell in accordance with the applicable military standard drawing or specification sheet. Individual crimp contacts may be removed or inserted using appropriate military standard contact insertion or withdrawal tools.

13.3.3.4 Contact arrangement. The contact positions are delineated in the applicable military standard drawing specification sheet.

MIL-HDBK-978-B (NASA)

**13.3 CONNECTORS, CIRCULAR, MINIATURE,
HIGH DENSITY, MIL-C-38999**



FIGURE 5. Straight plug, MIL-C-38999.

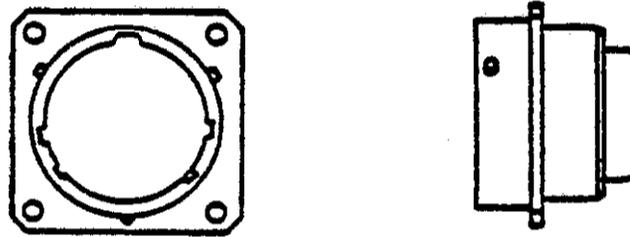


FIGURE 6. Box mounting receptacle, MIL-C-38999.

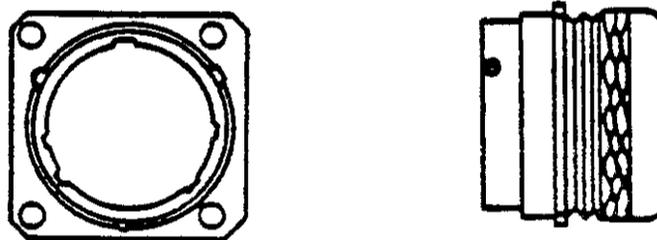


FIGURE 7. Wall mounting receptacle, MIL-C-38999.

MIL-HDBK-978-B (NASA)

**13.3 CONNECTORS, CIRCULAR, MINIATURE,
HIGH DENSITY, MIL-C-38999**

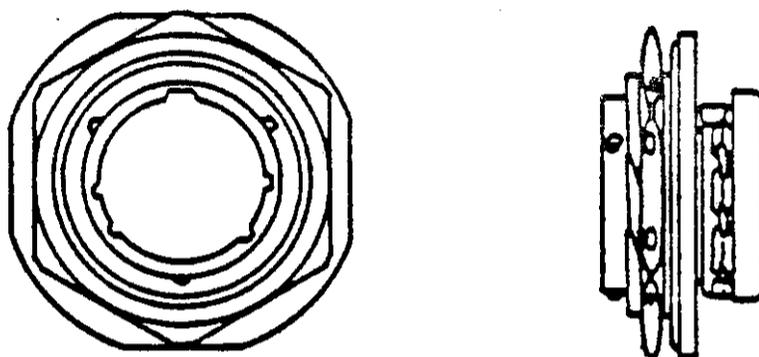


FIGURE 8. Jam-nut mounting receptacle, MIL-C-38999.



FIGURE 9. Solder mounting receptacle, MIL-C-38999.

13.3.3.5 Contacts. MIL-C-38999 removable contacts conform to MIL-C-39029. Dimensional data for solder contacts are given in MIL-C-38999. The solder cups for the nonremovable contacts are designed so that connector components will not be damaged and no liquid solder will escape during soldering. Care is required when removing crimp contacts so as not to damage the rear grommet.

13.3.3.6 Interfacial seal. Plugs and receptacles with pin inserts have a resilient face. This provides an interfacial seal with the hard face of the socket insert in the mated condition. This seal minimizes air voids between adjacent contacts and between contacts and the shell, thereby improving high-voltage performance at altitude. The seal also prevents entrance of moisture, salt fog, and fuels when the connector is mated.

MIL-HDBK-978-B (NASA)

**13.3 CONNECTORS, CIRCULAR, MINIATURE,
HIGH DENSITY, MIL-C-38999**

13.3.4. Military designation. Qualified connectors are procured by military standard drawings. The following is an example of a complete part number for a MIL-C-38999 connector. Basic drawings provide detailed information for connectors supplied to MIL-C-38999.

MS 27467	E	13	F	8	P	A
Basic MS drawing no.	Class:	Shell size	Finish:	Insert arrange- ment	Contact style:	Keying positions:
	E=Environment resisting		C-Anodic		P-pins S-sockets	A,B,C,D
	P=Potting, includes pot- ting form		D-Fused tin plate			No letter required for normal position.
	T=Environment resisting without rear accessories		E-Passivated (corrosion resistant steel only)			
	Y=Hermetically sealed		F-Conductive electro- less nickel coating			

13.3.5 Electrical characteristics.

13.3.5.1 Contact resistance. Contact resistance for mated contacts is often expressed as millivolt drop measured across the mated contact pair. The maximum allowable voltage drop across the mated contact pair is specified in MIL-C-38999 for various combinations of contact size, wire gauge, test current, and service class.

13.3.5.2 Working voltage or test voltage. The voltage rating of a connector decreases with increasing altitude. This parameter may be expressed as a test voltage or working voltage. The maximum voltage ratings are given in MIL-C-38999.

13.3.5.3 Insulation resistance. The insulation resistance requirements for MIL-C-38999 connectors vary between the different series and classes. The insulation resistance values are listed in MIL-C-38999. The insulation resistance decreases with increasing temperature. Insulation resistance requirements at elevated temperatures are presented in MIL-C-38999.

13.3.6. Environmental considerations.

13.3.6.1 Temperature. All MIL-C-38999 Series I and II connectors are capable of continuous operation within a temperature range of -65 to +150 °C. The maximum temperature for selected classes is +200 °C.

MIL-HDBK-978-B (NASA)

**13.3 CONNECTORS, CIRCULAR, MINIATURE,
HIGH DENSITY, MIL-C-38999**

13.3.6.2 Humidity. To assure engagement of the moisture seal, plugs and receptacles with pin contacts have a resilient face. The resilient interfacial seal provides individual contact seals in the mated condition to insure circuit isolation between contacts and between contacts and the shell. To assure an adequate seal at the wire end of the connector, only wires with the proper insulation dimensions should be used. The proper insulation sizes to achieve moisture seals are listed in MIL-C-38999.

13.3.6.3 Environmental qualification. MIL-C-38999 connectors are considered to be environment resistant. The performance requirements, including the environmental qualification tests are listed in MIL-C-38999.

13.3.7 Reliability considerations. These connectors have been widely used in military systems. Some problems that occasionally arise are contact retention failures and loss of electrical continuity in mated contact pairs.

Contact retention failures are most often due to improper assembly techniques or faulty contact retention systems in the connector. Operator training is usually sufficient to eliminate problems due to improper assembly techniques. Increased attention to manufacturing processes and quality control will generally eliminate faults in the contact retention system.

Electrical failures of the contacts are most often caused by contamination, improper heat treatment of the socket springs, or dimensions which are out of tolerance.

**13.4 CONNECTORS, RACK AND
PANEL, MIL-C-24308**

13.4 Rack and panel, MIL-C-24308.

13.4.1 Introduction. Connectors covered by this section are rectangular, nonenvironment-resisting and are available with solder or crimp type contacts. These connectors may be mated by being pushed together without the aid of a coupling mechanism or by use of screwlock hardware. Proper connector orientation during mating is accomplished by a polarized shell. Mounting holes provided in the connector shell, or screwlock hardware may be used to mount the connector to a rack or panel.

13.4.2 Usual applications. These connectors may be used with cables and are available with hoods and cable clamps to protect the assembled cable.

As their description suggests, these connectors are primarily used where a rack or drawer must plug into a panel. The mounting hardware and polarizing shells act as guides. These connectors are also available with float mounting hardware to aid in mating.

MIL-C-24308 connectors are available in six classes as follows:

G = General purpose

D = General purpose (spaceflight)

N = Nonmagnetic

M = Nonmagnetic (spaceflight)

H = Hermetic

K = Hermetic (spaceflight)

13.4.3 Physical configuration. A typical pair of polarized shell rack and panel connectors is shown in Figure 10.

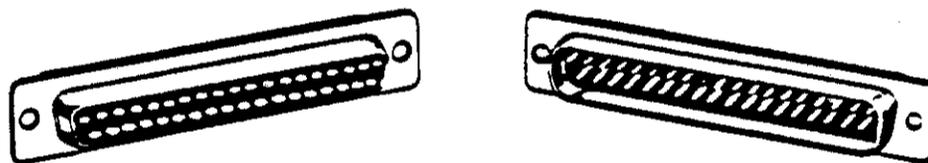
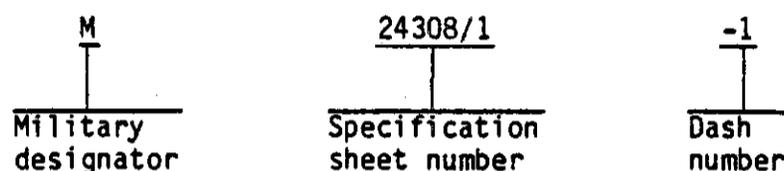


FIGURE 10. Polarized rack and panel connectors, MIL-C-24308.

13.4 CONNECTORS, RACK AND PANEL, MIL-C-24308

13.4.4 Military designation. Polarized rack and panel connectors meeting MIL-C-24308 are identified by military specification sheets. The military part number consists of the letter M, the basic number of the specification slash sheet, and a specific part number as follows:



13.4.5 Electrical characteristics.

13.4.5.1 Contact resistance limits. The electrical resistance of mated pairs of pin and socket contacts is controlled by the test methods and requirements of MIL-C-24308. The maximum allowable voltage drop across the mated pair of contacts at the required test current is specified in MIL-C-24308

13.4.5.2 Dielectric withstanding voltage. The connectors are designed to show no evidence of flashover between contacts or contacts and shell at the voltages specified in MIL-C-24308.

13.4.5.3 Insulation resistance. The rack and panel connectors are designed to have an insulation resistance of not less than 5,000 megohms under normal conditions. After being subjected to 10 days humidity conditioning, minimum insulation resistance of 1 megohm must be met.

13.4.6 Environmental considerations.

13.4.6.1 Operating temperature range. These connectors are suitable for operation throughout a temperature range of -55 to +125 °C.

13.4.6.2 Vibration. These connectors are designed to perform, when properly mated, over the range of mechanical vibration as specified in MIL-C-24308 without cracking, breaking or loosening of parts and to exhibit no loss of electrical continuity for the specified time period.

13.4.6.3 Mechanical shock. When properly mated, these connectors will perform without cracking, breaking or loosening of parts when subjected to the mechanical shock as specified in MIL-C-24308.

13.4.6.4 Moisture resistance. These connectors are not designed to seal against moisture accumulation. Condensation can form on contacts. The materials used will maintain 1000 megohm insulation resistance after exposure to high humidity, but the connectors are not tested for high potential at a high humidity state. They are tested for high potential only when no surface moisture is present.

MIL-HDBK-978-B (NASA)

**13.4 CONNECTORS, RACK AND
PANEL, MIL-C-24308**

13.4.7 Reliability considerations. This connector design is produced by many suppliers of commercial connectors. An emphasis on quality control by both the connector vendor and the user is desirable for these types of connectors which are to be used in aerospace systems. Connectors of this design have been used in commercial and military systems for many years, and the design is considered to be mature. Some problems that occasionally arise are a loss of electrical continuity in mated contact pairs and dimensions which are out of tolerance.

Electrical failures of the contacts are most often caused by contamination, improper heat treatment of the socket springs, or dimensions which are out of tolerance.

MIL-HDBK-978-B (NASA)

**13.5 CONNECTORS, CIRCULAR,
POWER, MIL-C-5015**

13.5 Circular, power, MIL-C-5015.

13.5.1 Introduction. This specification covers circular electrical connectors with solder or removable crimp contacts (both front and rear release).

The connector types chosen for standardization under this specification are those with rear release crimp removable contacts and those with non-removable solder type contacts.

The rear release crimp contact series connector is available in two classes as follows:

Class L - Fluid resistant

W - General purpose

The solder type contact series connector is available as follows:

Class R - Grommet seal

13.5.2 Usual applications. These connectors are generally used in high-power designs, such as power supplies. A contact range from size 0 to 16 is offered. Due to their high power capabilities, contact arrangements are less dense than in other connectors used in digital designs where space is critical and high power is not a design factor.

13.5.3 Physical construction. Coupling is accomplished with a threaded coupling nut on the plug which mates with threads on the receptacle. Insert alignment is assured through the use of key and keyway locators. The connectors are designed so that polarization of the mated pairs occurs prior to coupling.

Receptacles are available in cable-connecting, wall mount, box mount, and jam nut configurations.

Some accessories which are available for use with these connectors include cable clamps, shield terminations, 90 °C and 45 °C backshells, strain reliefs and stowage connectors.

13.5.3.1 Connector configurations. Typical connector configurations are as shown in Figures 11 through 15.

13.5.3.2 Contact arrangement. The contact positions are delineated in the applicable military standard drawing.

13.5.3.3 Contacts. Contacts conform to MIL-C-39029. Contacts are designed to prevent damage to the contact retention device and sealing device during insertion or removal of the contact and are designed to insure proper mating with their counterpart without damage.

MIL-HDBK-978-B (NASA)

**13.5 CONNECTORS, CIRCULAR,
POWER, MIL-C-5015**

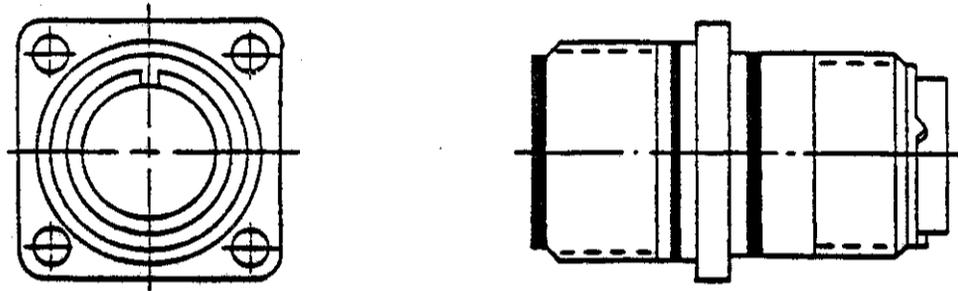


FIGURE 11. Wall mounting receptacle, MIL-C-5015.

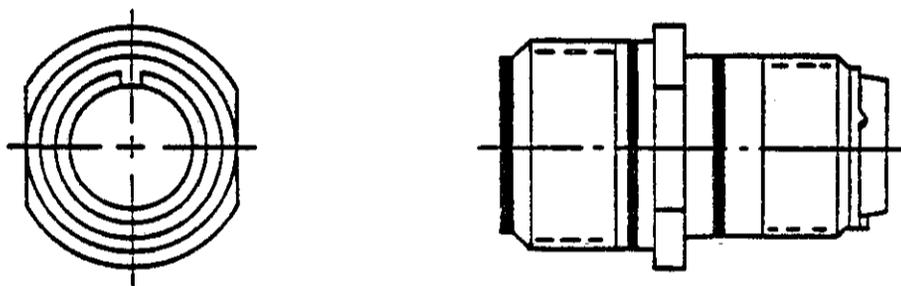


FIGURE 12. Cable-connecting receptacle, MIL-C-5015.

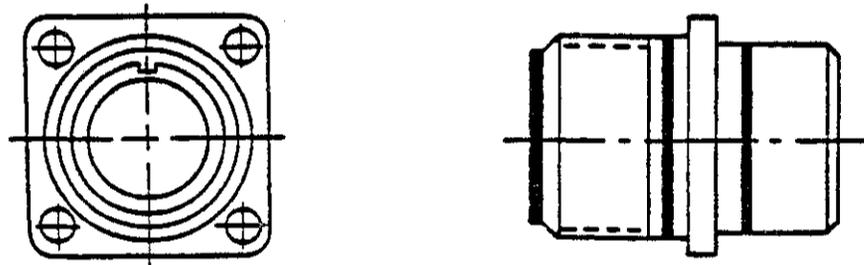


FIGURE 13. Box mounting receptacle, MIL-C-5015.

MIL-HDBK-978-B (NASA)

**13.5 CONNECTORS, CIRCULAR,
POWER, MIL-C-5015**

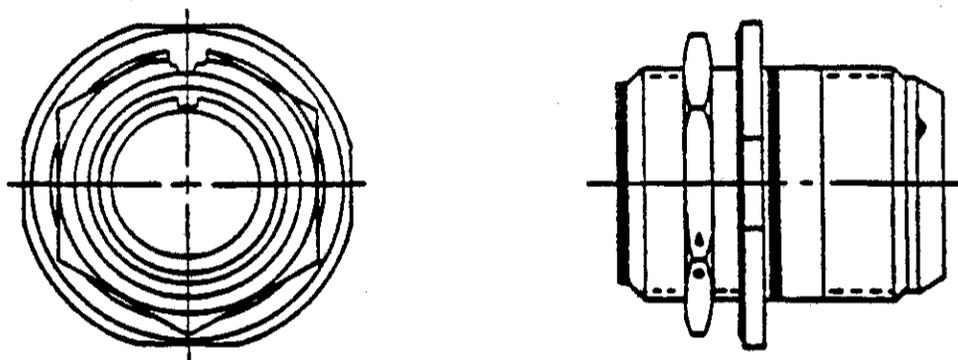


FIGURE 14. Jam nut receptacle, MIL-C-5015.

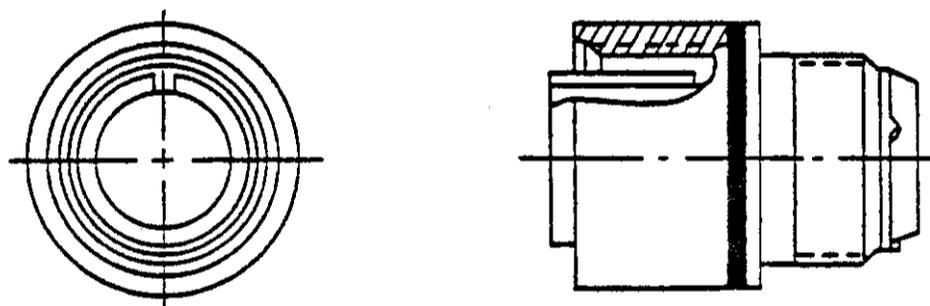


FIGURE 15. Straight plug, MIL-C-5015.

Contact insertion and removal tools are listed in MIL-C-5015. Crimp tools conform to M22520 series and applicable military standard drawings.

Crimp contacts are designed to permit individual insertion and removal.

13.5.3.4 Insert design and construction. Inserts are of voidless construction and are secured to prevent rotation within the shell. Removable inserts are keyed to prevent rotation. Slots and markings to allow for alternate clocking positions are as indicated in the applicable military standard. Inserts are installed in the position indicated by the part number.

13.5.3.5 Engagement seal. Connectors with pin inserts have an interfacial seal with raised sealing barriers around each pin contact. The barriers seal off moisture upon contact with the socket insulator mating face. Connector plug shells are provided with a static peripheral seal to insure shell to shell sealing.

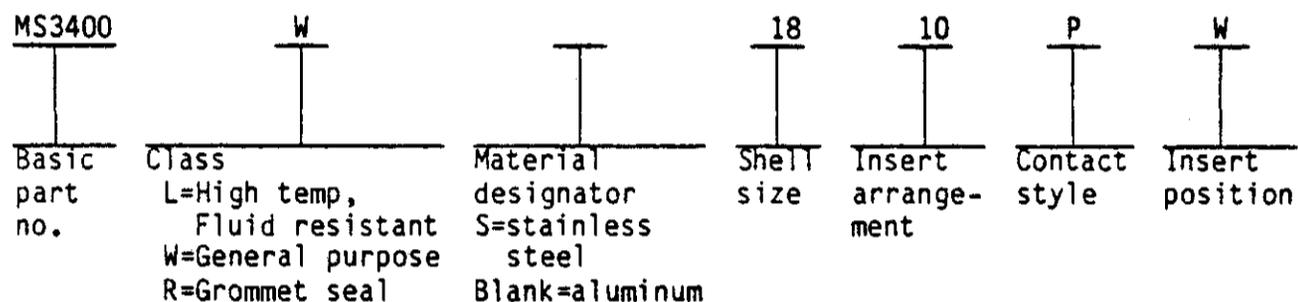
MIL-HDBK-978-B (NASA)

**13.5 CONNECTORS, CIRCULAR,
POWER, MIL-C-5015**

13.5.3.6 Wire range accommodations. The proper insulated wire diameters must be selected to assure an adequate moisture seal around the wire as it penetrates the rear grommet. The proper insulated wire diameters are listed in MIL-C-5015.

13.5.4. Military designation. The part number for qualified connectors procured in accordance with MIL-C-5015 conforms to the following example. Basic drawings provide detail information for connectors supplied to MIL-C-5015.

Example MS3400W 18 - 10P W



13.5.5 Electrical characteristics.

13.5.5.1 Contact resistance. Contact resistance for mated contacts is often expressed as a voltage drop measured across the mated contact pair. The maximum allowable voltage drop is specified in MIL-C-5015 for various combinations of contact size, wire gauge, and test current.

13.5.5.2 Working voltage. The maximum working voltage at sea level is specified in MIL-C-5015.

13.5.5.3 Test voltages. The maximum test voltages at sea level and altitude (70,000 ft.) are specified in MIL-C-5015.

13.5.5.4 Insulation resistance. Insulation resistance decreases with increasing temperature; the requirements at elevated temperature are specified in MIL-C-5015. Requirements for MIL-C-5015 connectors vary between classes and insulation resistance values are specified in MIL-C-5015.

13.5.6 Environmental considerations.

13.5.6.1 Temperature. These connectors are capable of continuous operation within a temperature range as follows:

Class L: -55 to +200 °C

R: -55 to +125 °C

W: -55 to +125 °C

**13.5 CONNECTORS, CIRCULAR,
POWER, MIL-C-5015**

The expected service life decreases with increasing temperature. Service life and hot spot temperature curves are presented in MIL-C-5015.

MIL-C-5015 connectors are considered to be environment resistant. The performance requirements, including the environmental qualification test requirements, are listed in MIL-C-5015.

13.5.7 Reliability considerations. These connectors have been widely used in military systems for many years, and the design is considered to be mature. Some problems that occasionally arise are contact retention failures, difficulty in intermating connectors supplied from different vendors, and loss of electrical continuity in mated contact pairs.

Contact retention failures are most often due to improper assembly techniques or faulty contact retention systems in the connector. Operator training is usually sufficient to eliminate problems due to improper assembly techniques. Increased attention to manufacturing processes and quality control will generally eliminate faults in the contact retention system.

Difficulty in mating connector halves which have been supplied from different vendors is often traced to dimensions which are out of tolerance.

Electrical failures of the contacts are most often caused by contamination, improper heat treatment of the socket springs, or dimensions which are out of tolerance.

MIL-HDBK-978-B (NASA)

**13.6 CONNECTORS, PRINTED
CIRCUIT, MIL-C-55302**

13.6 Printed circuit, MIL-C-55302.

13.6.1 Introduction. This section covers connectors and their accessories for printed circuit assembly.

13.6.2 Usual applications. These printed circuit connectors are for use with single-sided, double-sided and multilayer printed wiring boards conforming to MIL-STD-275, MIL-P-55110 and MIL-P-55424.

These connectors are designed for printed-wiring-board to printed-wiring-board or printed-wiring-board to cable interconnections of miniaturized equipment sub-assemblies with low power requirements. These connectors have an operating temperature range of -65 to +125 °C.

13.6.3 Physical construction. Figures 16 through 19 illustrate various types of printed circuit connectors.

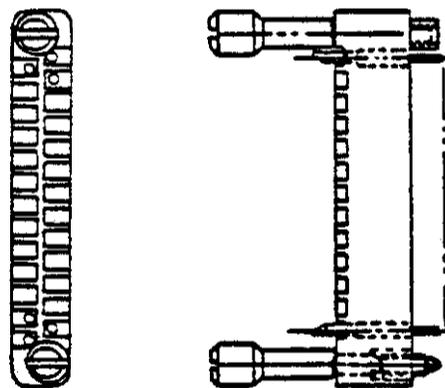


FIGURE 16. Plug with pin contacts and turning jackset shown (also available with socket contacts and alternate mounting hardware), MIL-C-55302.

MIL-HDBK-978-B (NASA)

13.6 CONNECTORS, PRINTED
CIRCUIT, MIL-C-55302

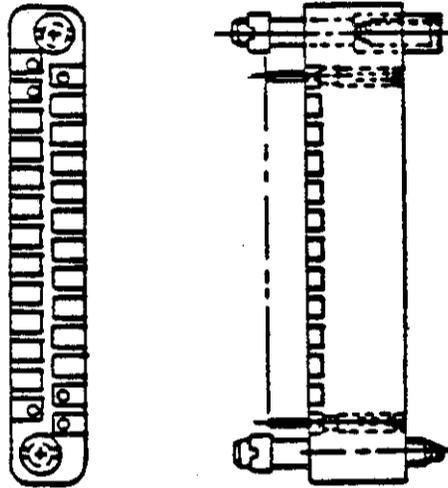


FIGURE 17. Receptacle with socket contacts and fixed jackset shown (also available with pin contacts and alternate mounting hardware), MIL-C-55302.

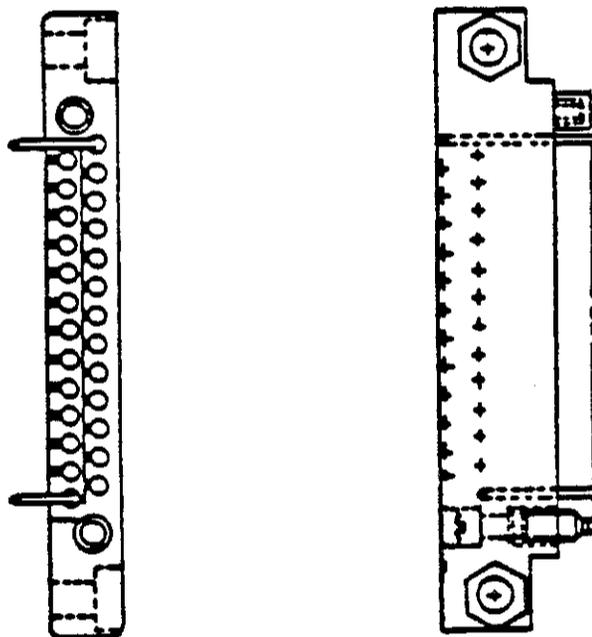


FIGURE 18. Right angle plug with pin contacts and fixed jackset shown (also available with alternate mounting hardware), MIL-C-55302.

**13.6 CONNECTORS, PRINTED
CIRCUIT, MIL-C-55302**

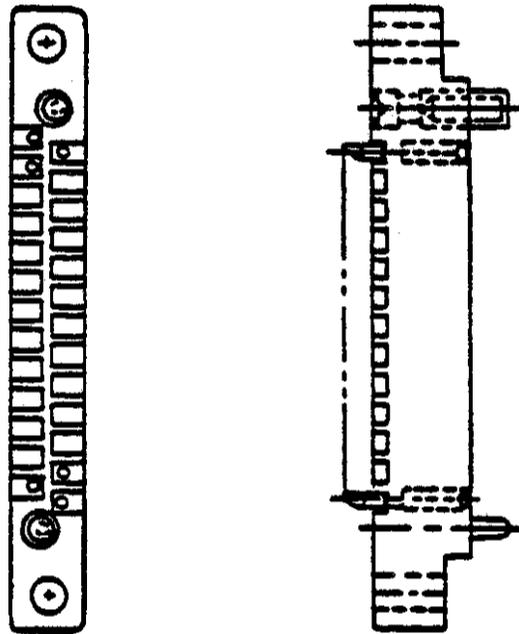


FIGURE 19. Receptacle with socket contacts, round guideset, and mounting ears (also available with alternate mounting hardware), MIL-C-55302.

13.6.3.1 Bodies. The printed circuit connector consists of two plastic bodies containing pin and socket contacts. They contain integral aligning features to assure proper mating of the connectors.

13.6.3.2 Contacts. Contacts may be either removable crimp type or solder type. The contact pairs have sufficient compliance to assure proper mating.

The contacts are designed to assure that the mating and unmating forces transmitted to the connection joining the contact to the board will not degrade the connection through usage.

The connectors covered herein have contacts spaced at 0.100 inch.

13.6 CONNECTORS, PRINTED
CIRCUIT, MIL-C-55302

13.6.3.3 Polarization. Polarization is accomplished through jackscrew or guide pin hardware, to ensure correct mating of the plug and receptacle.

13.6.3.4 Terminations. Figures 20 thru 23 illustrate various types of terminations available for these connectors.

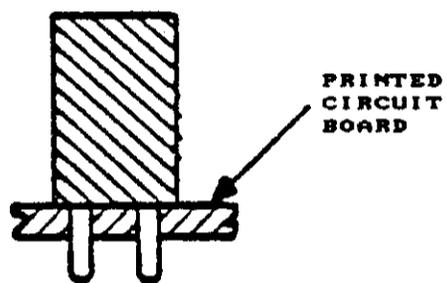


FIGURE 20. Dip solder or flex circuit termination.

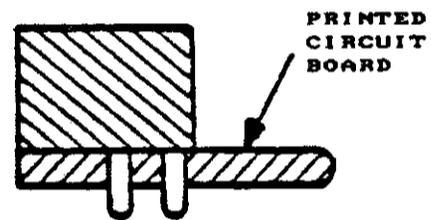


FIGURE 21. Dip solder termination (right angle).



FIGURE 22. Solder cup.



FIGURE 23. Removable crimp contacts.

MIL-HDBK-978-B (NASA)

**13.6 CONNECTORS, PRINTED
CIRCUIT, MIL-C-55302**

13.6.3.5 Connector assembly. Table IV identifies the connector by specification sheet number and associates it with its configuration type, contact quantities, and terminations available. Refer to MIL-STD-975 for connector selections.

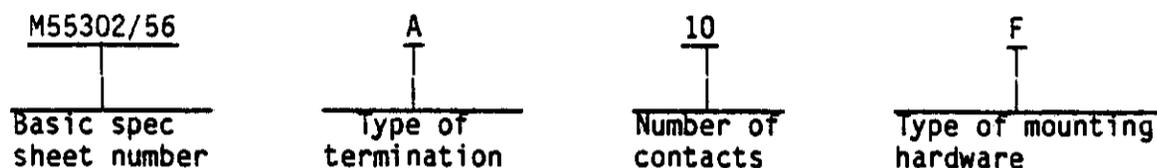
TABLE IV. Connector configurations

Spec Sheet Number	Configuration Figure No.	Contact Quantities	Termination Type-Figure No.			
			20	21	22	23
M55302/55	16	10 - 70	X		X	
M55302/56	17		X		X	
M55302/57	18			X		
M55302/58	19		X		X	
M55302/59	18	90 - 120		X		
M55302/60	19		X		X	
M55302/61	18	10 - 70		X		
M55302/62	17		X		X	
M55302/63	16		X		X	
M55302/64	17		X		X	
M55302/65	19					X
M55302/66	17					X

MIL-HDBK-978-B (NASA)

**13.6 CONNECTORS, PRINTED
CIRCUIT, MIL-C-55302**

13.6.4. Military designation. Qualified connectors are procured through military specification sheets. The following is an example of a complete number:



13.6.5 Electrical characteristics. The electrical characteristics are as specified in Table V.

TABLE V. Electrical characteristics

Spec Sheet Number	Dielectric Withstanding Voltage		Contact Resistance		Contact Current Rating
	Sea Level	Altitude	Individual	Mated Pair	
M55302/55 thru M55302/66	1000 V(RMS)	300 V(RMS)	0.010 Ohm	0.020 Ohm	5.0 Amps maximum

13.6.6 Environmental characteristics. These connectors are not designed to be environment resistant. The operating environment for these connectors is specified in MIL-C-55302.

13.6.7 Reliability considerations. These connectors are widely used in military and aerospace systems. Some problems that occasionally arise are contact retention failures, loss of electrical continuity in mated contact pairs, and dimensions which are out of tolerance.

Contact retention failures are most often due to improper assembly techniques or faulty contact retention systems in the connector. Operator training is usually sufficient to eliminate problems due to improper assembly techniques. Increased attention to manufacturing processes and quality control will generally eliminate faults in the contact retention system.

Electrical failures of the contacts are most often caused by contamination, improper heat treatment of the socket springs, or dimensions which are out of tolerance.

MIL-HDBK-978-B (NASA)

**13.7 CONNECTORS, CONTACTS, ELECTRICAL
CONNECTOR, MIL-C-39029**

13.7 Contacts, electrical connector, MIL-C-39029.

13.7.1 Introduction. These contacts are removable crimp type pin and socket contacts intended for use in electrical connectors.

13.7.2 Usual applications. These contacts are normally supplied with the connector with which they are intended to be used. Removable contacts are also available separately, and may be obtained under the military part number.

13.7.3 Physical construction.

13.7.3.1 Typical configurations. MIL-C-39029 contacts are available in pin and socket configurations as shown in Figures 24 and 25. Wires are terminated to the contacts by means of a crimp joint.



FIGURE 24. Pin contact with crimp termination, MIL-C-39029.

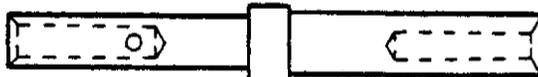
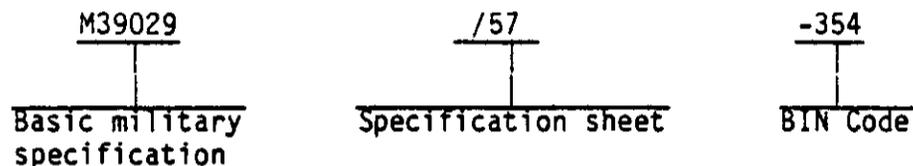


FIGURE 25. Socket contact with crimp termination, MIL-C-39029.

MIL-HDBK-978-B (NASA)

**13.7 CONNECTORS, CONTACTS, ELECTRICAL
CONNECTOR, MIL-C-39029**

13.7.4 Military designation. The military part number for qualified contacts in accordance with MIL-C-39029 conforms to the following example:



13.7.5 Electrical characteristics. Electrical characteristics are in accordance with the provisions of MIL-C-39029 and the applicable military connector specifications.

13.7.6 Environmental considerations. The environmental considerations for the contacts follow the environmental considerations for the electrical connectors in which the contacts are intended to be installed. The environment resistant characteristics of the contacts are covered by the environment resisting requirements of the applicable connector specifications and MIL-C-39029.

13.7.7 Reliability considerations. These contacts are widely used in many connectors. The most common contact failures are due to loss of electrical continuity in mated contact pairs. These failures are most often caused by contamination, improper heat treatment of the socket springs, or dimensions which are out of tolerance. Increased awareness of contamination control during assembly and use of the connector can alleviate these problems. Other common contact failures are caused by plating defects and improper hardness of the crimp barrel.

MIL-HDBK-978-B (NASA)

**13.8 CONNECTORS, CIRCULAR,
HEAVY DUTY, MIL-C-22992**

13.8 Circular, heavy duty, MIL-C-22992.

13.8.1 Introduction. This specification covers heavy duty waterproof circular connectors with threaded coupling mechanisms and solder contacts.

Available service classes include Class C (pressurized) and Class R (environment resisting).

Plugs are available in two configurations. Straight plugs are normally used to make cable to box connections. Cable connecting plugs without coupling rings (that perform the same function as in-line, cabled receptacles) are used for making cable to cable interconnections.

Receptacles are available with wall flange mounts, box flange mounts, wall jam-nut mounts, and box jam-nut mounts.

Available accessories include protective caps, stowage receptacles, and cable sealing adapters.

13.8.2 Usual applications. The connectors are intended for use on ground support equipment in environment resisting applications. The connectors are waterproof and are suited for use in high humidity environments. The connectors are designed to withstand abuse due to rough handling.

These connectors are designed to have an operating temperature range of -55 to +125 °C.

13.8.3 Physical construction. Figures 26 through 31 illustrate various MIL-C-22992 connectors.

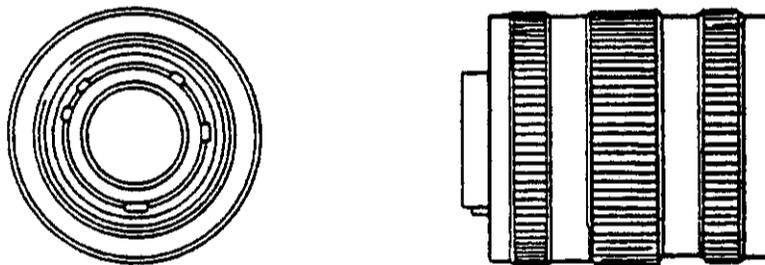


FIGURE 26. Straight plug, MIL-C-22992.

MIL-HDBK-978-B (NASA)

**13.8 CONNECTORS, CIRCULAR,
HEAVY DUTY, MIL-C-22992**

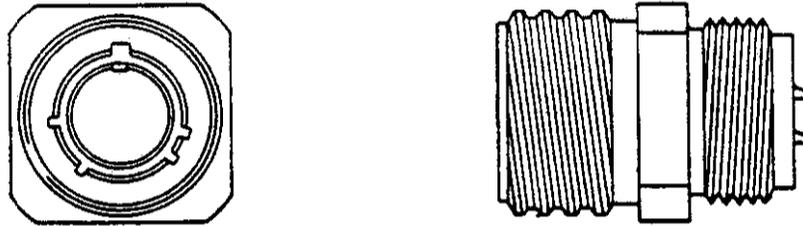


FIGURE 27. Cable connecting plug without coupling ring
(cabled receptacle), MIL-C-22992.

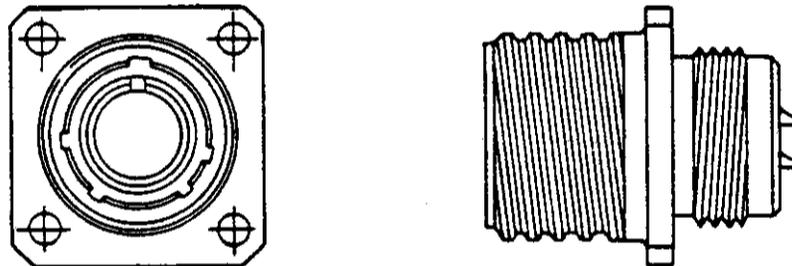


FIGURE 28. Wall mount receptacle, MIL-C-22992.

MIL-HDBK-978-B (NASA)

**13.8 CONNECTORS, CIRCULAR,
HEAVY DUTY, MIL-C-22992**

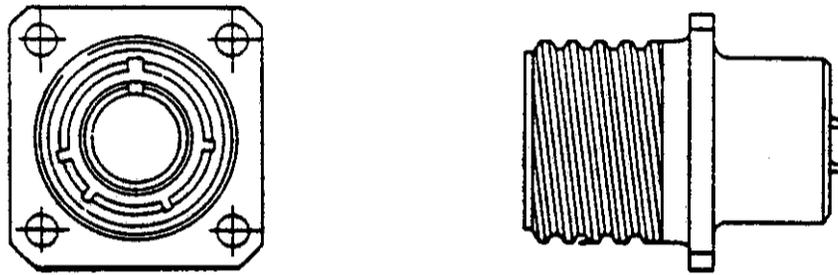


FIGURE 29. Box mount receptacle, MIL-C-22992.

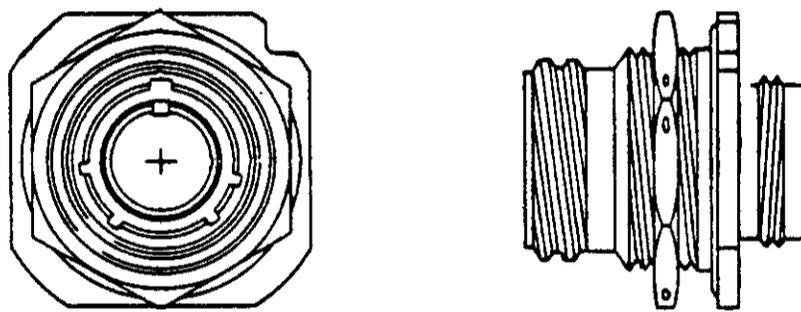


FIGURE 30. Wall jam-nut receptacle, MIL-C-22992.

MIL-HDBK-978-B (NASA)

**13.8 CONNECTORS, CIRCULAR,
HEAVY DUTY, MIL-C-22992**

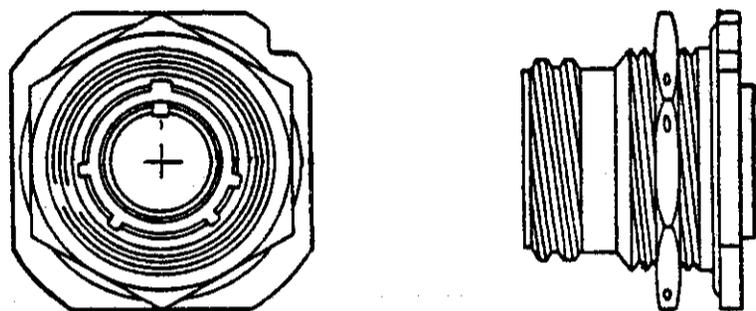


FIGURE 31. Box jam-nut receptacle, MIL-C-22992.

13.8.3.1 Insert design and construction. Inserts are of voidless construction and are secured to prevent rotation within the shell. The inserts are not removable from the shell for Classes C and R. The inserts are installed in the position specified on the applicable Military Standard.

13.8.3.2 Contacts. Solder contacts are utilized for Class C and Class R connectors. Contact sizes 0, 4, and 8 may be designed so that the contacts may be removed from the connector to facilitate soldering. Contact sizes 12 and 16 are not removable from the connector. Contact design is in accordance with MIL-C-22992 and MIL-C-39029.

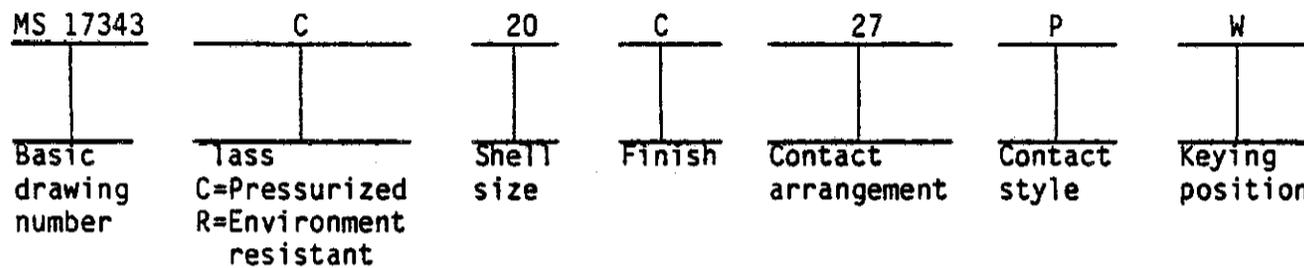
13.8.3.3 Coupling. Coupling is accomplished by clockwise rotation of the coupling ring. Uncoupling is accomplished by counterclockwise rotation of the coupling ring. The coupling rings are knurled or fluted to provide a gripping surface.

13.8.3.4 Polarization. Polarization is accomplished by matched integral keys and keyways of counterpart connectors. Only connectors with matching keys and keyways will mate. To assure proper contact alignment during connector mating, polarization and engagement of the shells occurs prior to engagement of the contacts.

MIL-HDBK-978-B (NASA)

**13.8 CONNECTORS, CIRCULAR,
HEAVY DUTY, MIL-C-22992**

13.8.4 Military designation. The military standard part numbers for qualified connectors procured in accordance with MIL-C-22992 conform to the following example. Basic drawings provide detailed information for connectors supplied to MIL-C-22992.



13.8.5 Electrical characteristics.

13.8.5.1 Contact resistance. The electrical resistance of mated pairs of pin and socket contacts is controlled by the test methods and requirements of MIL-C-22992. The maximum allowable voltage drop across the mated contact pair is specified in MIL-C-22992 for the applicable contact size.

13.8.5.2 Insulation resistance. The insulation resistance of MIL-C-22992 connectors is 5,000 megohms when measured in accordance with MIL-C-22992.

13.8.6 Environment considerations.

13.8.6.1 Temperature. These connectors are rated for operation within a temperature range of -55 to +125 °C. The upper temperature limit is the maximum hot spot temperature resulting from any combination of ambient temperature and the temperature rise induced by electrical loads.

13.8.6.2 Fluid immersion. To ensure resistance to immersion in fluids, the connector shells are equipped with sealing gaskets. These connectors are designed to withstand the effects of immersion in water, petroleum based hydraulic fluid, and aircraft lubricating oil.

13.8.7 Reliability considerations. These connectors have been widely used in heavy duty ground support equipment. Some problems that occasionally arise are improper keying or clocking of the connectors, difficulty in intermating connectors supplied from different vendors, and loss of electrical continuity in mated contact pairs.

Keying, clocking, and intermateability problems can be eliminated with better control over the manufacturing process and increased emphasis on quality control.

Electrical failures of the contacts are most often caused by contamination, improper heat treatment of the socket springs, or dimensions that are out of tolerance.

MIL-HDBK-978-B (NASA)

**13.9 CONNECTORS, CIRCULAR,
NASA 40M SERIES**

13.9 Circular, NASA 40M series.

13.9.1 Introduction. These specifications cover environment resistant and hermetic bayonet coupling circular connectors with removable crimp or solder type contacts.

Receptacles are available with flange mounts, solder mounts, jam-nut mounts, and thru-bulkhead jam-nut mounts.

These connectors are available in accordance with the following specifications:

40M 38277	Connectors, Electrical, Miniature, High Density, Environment Resisting
40M 38298	Connectors, Electrical, Special, Miniature, Circular, Environment Resisting, 200 °C
40M 39569	Connectors, Electrical, Miniature Circular, Environment Resisting, 200 °C

13.9.2 Usual applications. These connectors are intended for use on space vehicles while exposed to earth atmosphere, space vacuum, or crew compartment environments. These connectors are similar to the connectors specified by MIL-C-26482 and MIL-C-38999, except for the additional requirements which make these devices suitable for operation in a space environment.

13.9.3 Physical construction. Figures 32 through 36 illustrate various 40M series circular connectors.



FIGURE 32. Straight plug.

MIL-HDBK-978-B (NASA)

**13.9 CONNECTORS, CIRCULAR,
NASA 40M SERIES**

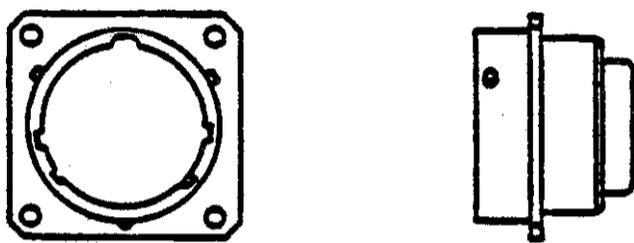


FIGURE 33. Receptacle with flange mount.

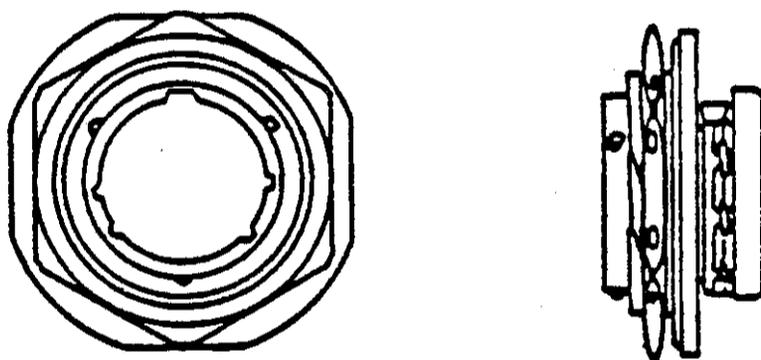


FIGURE 34. Jam-nut mount receptacle.

MIL-HDBK-978-B (NASA)

**13.9 CONNECTORS, CIRCULAR,
NASA 40M SERIES**

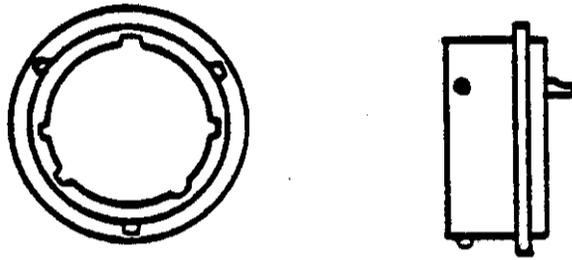


FIGURE 35. Solder mount receptacle.

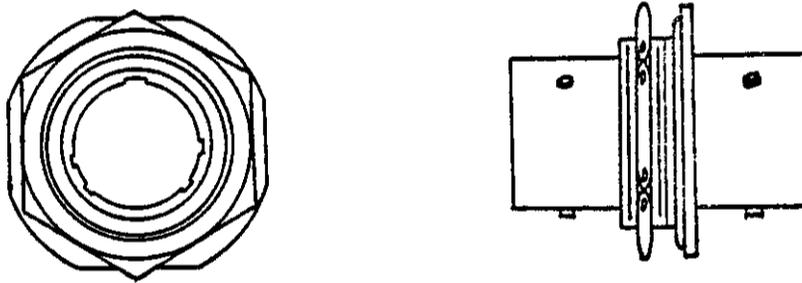


FIGURE 36. Bulkhead receptacle.

MIL-HDBK-978-B (NASA)

**13.9 CONNECTORS, CIRCULAR,
NASA 40M SERIES**

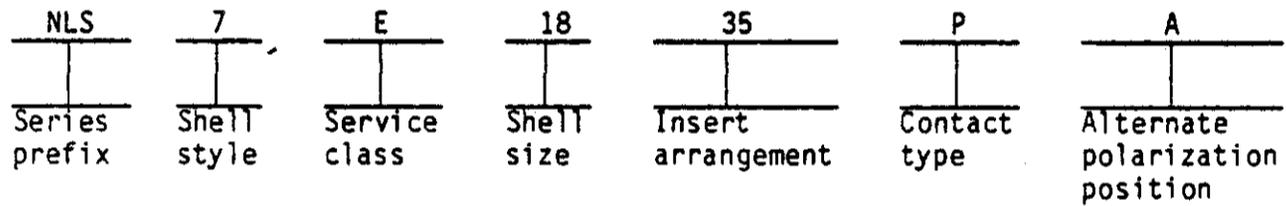
13.9.3.1 Flammability, odor, and outgassing. The connectors are capable of meeting the NASA requirements for flammability, odor, and outgassing for spaceflight applications.

13.9.3.2 Explosive atmosphere. The connectors are capable of operating in an explosive atmosphere without burning or igniting the atmosphere. The connectors are capable of meeting the explosive atmosphere requirements as specified in the NASA 40M series specifications.

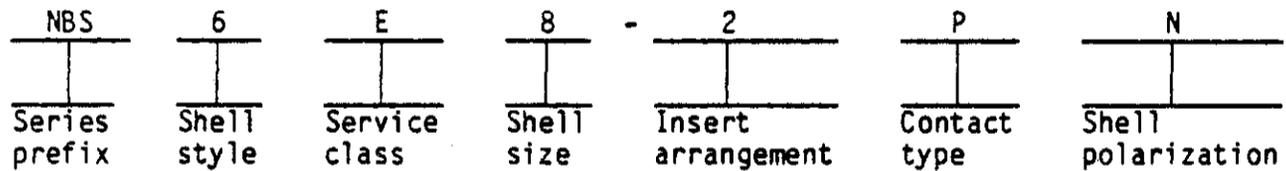
13.9.3.3 Stress corrosion prevention and control. The materials and processes used in the construction of the connectors are controlled in order to prevent and control the occurrence of stress corrosion.

13.9.4 MSFC designations. The Marshall Space Flight Center part numbers for connectors procured in accordance with the following specifications are as indicated in the following examples:

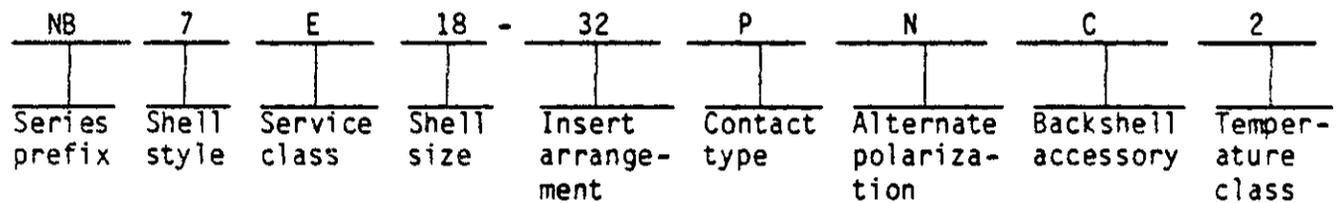
40M 38277



40M 38298



40M 39569



MIL-HDBK-978-B (NASA)

**13.9 CONNECTORS, CIRCULAR,
NASA 40M SERIES**

13.9.5 Electrical characteristics. The electrical characteristics are similar to those for MIL-C-26482 and MIL-C-38999 connectors, and are as specified in the 40M specifications.

13.9.6 Environmental considerations. The environment resisting characteristics are similar to those for MIL-C-26482 and MIL-C-38999 connectors. Additional requirements as outlined in 13.9.3 herein and as specified in the 40M specifications ensure that these connectors are suitable for space flight applications.

13.9.7 Reliability considerations. These connectors are similar to those as specified in MIL-C-26482 and MIL-C-38999, and are subject to the same reliability considerations see 13.2.7 and 13.3.7.

MIL-HDBK-978-B (NASA)

**13.10 RACK AND PANEL,
NASA GSFC-S-311 SERIES**

13.10 Rack and panel, NASA GSFC-S-311 series.

13.10.1 Introduction. Connectors covered in this section are rectangular and nonenvironment-resisting. These connectors may be mated by being pushed together without the aid of a coupling mechanism or by use of screwlock hardware. Proper connector orientation during mating is accomplished by a polarized shell. Mounting holes provided in the connector shell, or screwlock hardware may be used to mount the connector to a rack or panel.

13.10.2 Usual applications. These connectors may be used with cables and are available with hoods and cable clamps to protect the assembled cable.

As their description suggests, these connectors are primarily used where a rack or drawer must plug into a panel. The mounting hardware and polarizing shells act as guides. These connectors are also available with float mounting hardware to aid in mating.

GSFC S-311-P-4/07 connectors have high density contact arrangements, and are intended for spaceflight use. These connectors utilize removable crimp contacts and are available with two levels of residual magnetism.

A = residual magnetism not specified
B = 200 gamma

GSFC S-311-P-4/09 connectors have standard density contact arrangements, and are intended for spaceflight use. These connectors utilize removable crimp contacts and are available with two levels of residual magnetism.

A = residual magnetism not specified
B = 200 gamma

GSFC S-311-P10 connectors are intended for spaceflight use and are available with nonremovable coaxial, high voltage and solder type power contacts. These connectors are available with three levels of residual magnetism.

B = 200 gamma
C = 20 gamma
D = 2 gamma

**13.10 RACK AND PANEL,
NASA GSFC-S-311 SERIES**

13.10.3 Physical construction. A typical pair of polarized shell rack and panel connectors is shown in Figure 37.

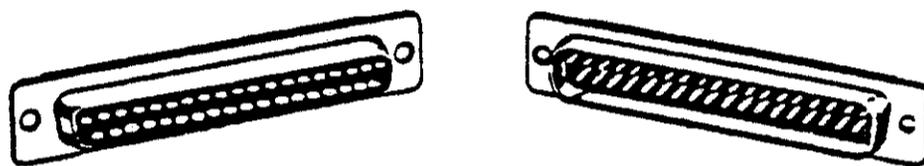


FIGURE 37. Polarized rack and panel connectors, GSFC-S-311.

13.10.4 NASA designation. High density polarized shell rack and panel connectors meeting GSFC-S-311-P-4/07 are identified by the GSFC part number as shown below:

311P407	-	1	-	P	-	B	-	12
GSFC		Contact		Contact		Residual		Mounting
Prefix		arrangement		type		magnetism		hole diameter

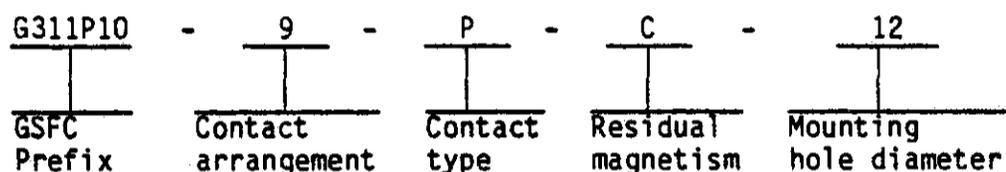
Standard density polarized shell rack and panel connectors meeting GSFC-S-311-P-4/09 are identified by the GSFC part number as shown below:

311P409	-	1	-	P	-	B	-	12
GSFC		Contact		Contact		Residual		Mounting
Prefix		arrangement		type		magnetism		hole diameter

MIL-HDBK-978-B (NASA)

**13.10 RACK AND PANEL,
NASA GSFC-S-311 SERIES**

Polarized shell rack and panel connectors with coaxial, high voltage and power contacts meeting GSFC-311-P-10 are identified by the GSFC part number as shown below:



13.10.5 Electrical characteristics. The electrical characteristics are similar to those for MIL-C-24308 connectors, and are specified in the GSFC-S-311 specifications.

13.10.6 Environmental considerations. The environmental resistor characteristics are similar to those for MIL-C-24308 connectors. These connectors are not designed to seal against the environment.

13.10.7 Reliability considerations. This connector design has been produced in a similar military version (MIL-C-24308) by many suppliers for many years, and the design is considered to be mature. Some problems that occasionally arise are a loss of electrical continuity in mated contact pairs and dimensions which are out of tolerance.

Electrical failures of the contacts are most often caused by contamination, improper heat treatment of the socket springs, or dimensions which are out of tolerance.

14.1 CONNECTORS, GENERAL

14. CONNECTORS, COAXIAL, RADIO FREQUENCY

14.1 General.

14.1.1 Introduction. This section contains information covering coaxial, radio frequency (rf) connectors included in MIL-STD-975 NASA Standard Electrical, Electronic, and Electromechanical (EEE) Parts List for use in Grade 2 applications.

Early military specifications lacked definition of the connectors in terms of their rf characteristics. Though dimensions were spelled out, manufacturing controls did not guarantee rf performance because variations in dielectric materials and tolerance fits of metal parts in the assembly can completely alter rf behavior. As a result, many users issued specifications reflecting their particular application needs; thus, making standardization impossible, creating confusion, and making correct field replacement extremely difficult.

MIL-C-39012 is a rf connector specification which defines the electrical characteristics and delineates the mating face dimensions. Recent additions to this specification are categories C and D which standardize cable strip dimensions and in some types, parts connecting to the cable are defined.

The rf connectors can be classified into specific series using several criteria such as size, coupling method, electrical characteristics, and applications such as high voltage or close impedance. The connectors in this section are classified by size.

14.1.1.1 Applicable military specifications. MIL-C-39012, Series, N, TNC, and SMA.

14.1.2 General definitions. The following is a list of terms which are commonly used with rf connectors. Refer to Section 13 Panel Connectors, for additional definitions applicable to connectors in general.

Jack. A jack is the mating unit for a plug and all mating features fit inside the plug when mated. It is also essential to have means for securing it to a cable. There are three types of jacks. A cable jack is secured to the end of a cable. A panel jack is secured to a cable but mounted on a panel by a square flange. A bulkhead jack is mounted on a panel by means of a shoulder and a hex nut.

Plug. The term plug defines the mating characteristics and can be broadly stated as that unit which, when mated, encompasses or fits over its mate. It is attached to the end of the cable and usually has no other means of mounting. It is called a cable plug although it is sometimes referred to as the male connector because it generally contains the male contact.

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14.1 CONNECTORS, GENERAL

Receptacle. A receptacle is similar to a jack without the cable clamping parts. The receptacle is open wired with the center conductor soldered onto the unit. The receptacle is mounted to a panel by means of a mounting flange or to a bulkhead by means of a shoulder and hex nut. Receptacles usually have female center contacts.

Semirigid cable connectors. This term refers to a connector that accepts a coaxial cable with a metallic outer jacket. Copper is commonly used for the outer jacket. However, it is also available in aluminum and stainless steel. The dielectric is polytetrafluoroethylene (Teflon) and the inner conductor is silver-plated solid copper wire.

Shorting plugs. A shorting plug is a unit with the mating features of a plug or receptacle which will short out the center contact to the body of the connector. A nonshorting plug is similar to the shorting plug without the center contact and has an added insulating backing disk.

14.1.3 General device characteristics. Series TNC, N, and SMA connectors are covered separately in subsection 14.2.

14.1.4 General parameter information. This subsection contains information on four electrical parameters generally associated with rf connectors as opposed to multipin connectors. The parameters are voltage standing wave ratio, insertion loss, rf leakage, and corona level.

14.1.4.1 Voltage standing wave ratio (VSWR). Any impedance mismatch in an rf transmission line will reflect energy that, in turn, will set up standing waves along the line with maximums and minimums occurring at one-quarter wavelength intervals. The VSWR is the ratio of the maximum to the minimum of these standing wave voltages.

The rf connectors are usually a compromise design in which one desirable characteristic is sacrificed to some extent in favor of another. This is especially true with voltage rating and VSWR. For example, a 5000 V connector does not have the broadband VSWR performance of a 500 V connector. VSWR characteristics are usually not measured for high-voltage connectors. On the other hand, a broadband connector with a VSWR of 1.2 at 10 GHz would not have high voltage (5000 V) characteristics. Long leakage paths in high-voltage connectors usually upset broadband VSWR performance due to characteristic impedance change.

14.1.4.2 Rf insertion loss. Insertion loss of a mated connector pair is defined as the increase of a loss due to the insertion of a mated connector pair in a cable. This includes the reflection losses to the cable and the dissipating losses in the pair.

Losses in an rf transmission line can be a design consideration but in practice, losses in connecting cables are large enough to make connector loss insignificant. For example, an N connector has an insertion loss of only 0.05 dB at

14.1 CONNECTORS, GENERAL

10 GHz, but RG-8/U cable has a loss of 1 dB per foot. Similarly, transmission loss of cables usually masks that of a connector. A connector VSWR of 1.35 would result in transmission loss of less than 0.1 dB, as compared with 1 dB per foot cable loss. The insertion loss varies with the square root of the frequency.

14.1.4.3 Rf leakage. Rf leakage describes both the loss of internal energy from a mated connector pair and the entrance of energy into the mated connector pair. Coaxial connectors have rf leakage values of 60 to 90 dB down from the signal level depending on the type of connector. But generally the shielding, even on bayonet-coupled units, is such that connector leakage is less than that introduced into the transmission system by a typical coaxial cable. For example, the leakage of a standard RG-59/U is about 30 dB down. In applications where rf leakage is critical, it is best to use triaxial connectors and cables or precision connectors with solid sheathed cables. The leakage is about 60 dB down for the triaxial equivalent of RG-59/U and at least 120 dB down for the precision connectors.

14.1.4.4 Corona level. Corona is the result of ionization of air. Corona tests are usually specified at 70,000 feet and are used to detect the presence of air pockets in the connector's dielectric and in the insulation in the cable. A high corona level can cause a sustained electrical discharge which can damage the connector and cable assembly.

14.1.5 General guides and charts. Figures 1 and 2, and Table I relate frequency range, voltage rating and RG cables used, respectively, for various connector series.

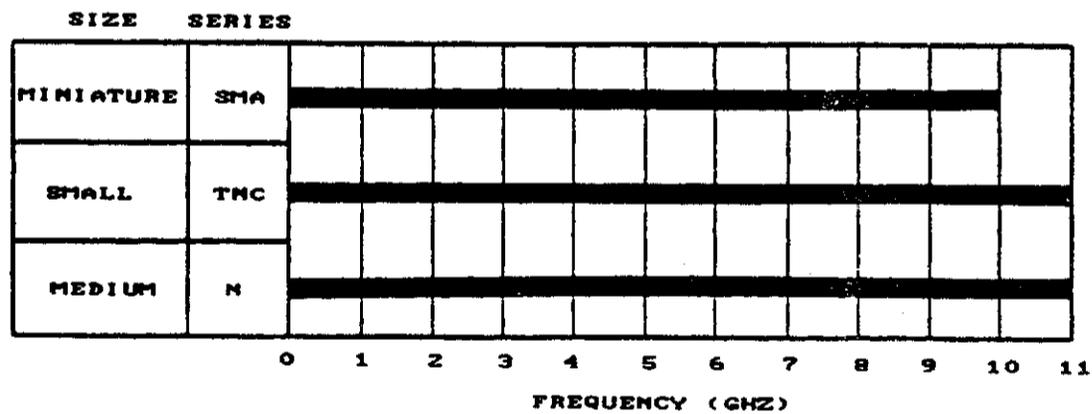


FIGURE 1. Frequency range vs series and size (typical).

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14.1 CONNECTORS, GENERAL

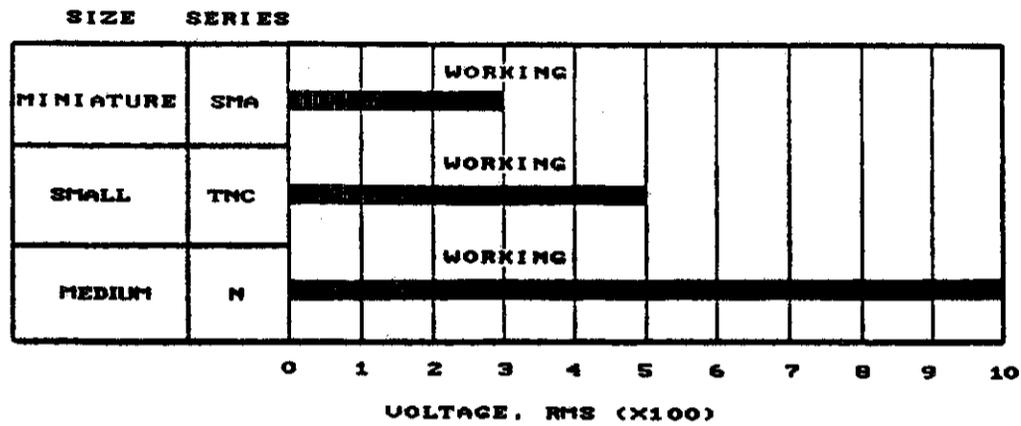


FIGURE 2. Voltage vs series and size (typical) at sea level.

TABLE I. Typical RG cables used with connectors

Size	Series	Cable OD	Typical RG cables used	Coupling	VSWR (typical)	Max Temp ^{1/} (connector)	Weather proof
Mini-ature	SMA	Up to 0.150	RG 178 RG 316	Threaded	1.2	200 °C	Yes
Small	TNC	0.150 to 0.350	RG 58, 141, 142	Threaded	1.3	100 °C	Yes
Medium	N	0.350	RG 213, 214, 215	Threaded	1.35	200 °C	Yes

^{1/} Maximum temperature will depend on the maximum temperature of the cable that is used with the connectors.

14.1.6 General reliability considerations.

14.1.6.1 Design considerations. Generally, one of the following objectives takes precedence of a particular coaxial line connector.

- a. The connector must be designed to have the same characteristic impedance as the mating cable. The objective is to make the connector an electrically homogeneous extension of the cable. This is almost invariably done in the frequency range above 1000 MHz.

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14.1 CONNECTORS, GENERAL

- b. The connector must be designed to allow the cable to take its maximum rated power. Expansion, caused by temperature, may cause a discontinuity by separating the cable from its clamping device. Designs using large contact areas should be used. It is also recommended that the center conductor of a connector be mechanically held in a fixed position (captive contact construction).
- c. The connector must be designed to allow the cable to take its full peak voltage rating (e.g., pulse cables). To accomplish this objective, physical discontinuities (steps in conductor diameters, etc.) where high voltage gradients may occur, must be kept to a minimum in number and size. Also, because of their higher electrical strength, dielectrics other than air are preferable throughout the connector. Provisions should be made to avoid the development of air pockets at the mating boundaries of connector pairs.
- d. The coupling mechanism must be highly functional to do the service intended. Where long, massive cables are to be joined, the coupling nut and associated retaining rings must be correspondingly strong. Where frequent movement or vibration is anticipated, the joining must be by strong, positive, vibration-free means.

14.1.6.2 Assembly considerations.

Dielectric joints. Where assembly instructions show butting of the cable and connector dielectrics, every precaution should be taken that the assembly method insures a positive butt. Where the connector is to be used at high frequency, where a low VSWR is a design-assembly aim, the development of air pockets, loose butt joints, or rounded corners of the dielectric will give rise to mismatch which is proportional to frequency.

If the assembly is of a high voltage cable, for pulse applications, air pockets or loose joints materially reduce the peak voltage capability of the entire connector. Loose butt joints, usually develop unless the dielectric trimming process is one of the last assembly operations. The clamping mechanism on the outer conductor should stress the butt joint.

Rounded corners usually develop either due to excess heating during soldering or through a mistaken notion that all "sharp edges should be avoided."

It is extremely important that dielectrics should be cut at a perfect right angle to the inner conductor. No notches should be permitted.

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Air pockets between the inner conductor and the dielectric of the cable usually develop due to excess heat when soldering the center contact of the connector onto the inner conductor of the cable. Some of the dielectric is softened, and through movement of the inner conductor, a larger hole is formed.

Center pin alignment. Precautions should be taken that the center contact of the connector rests at its proper lateral position.

In many connectors, the exact axial distance between a point on the connector shell and the tip of the pin is an electrical matching circuit. This is the case, for example, in Type N connectors where the male pin steps down before entering the female pin, of the mating connector, leaving a deliberate radial notch which is compensated for by the overhung iris in the ID of the outer conductor.

Many times, a misalignment results from assembling connectors to both ends of a relatively long cable while it is coiled. When it is uncoiled, the ends of the center conductor may assume a different position with respect to the ends of the outer braid.

For similar reasons, connectors should not be assembled to a cable, or replaced on a cable, under temperature extremes.

14.1.6.2.1 Soldering operations. In general, joining the center contact of the connector to the inner conductor of the cable constitutes the only soldering operation.

There are two major precautions to observe.

- a. A good solder bond should be made between the pin and the cable inner conductor over the entire length of the cable conductor that extends into the pin. Otherwise, a significant inductive reactance can be created. (The hole in the pin and the cable center conductor can form the conductors of a small, short-circuited coaxial line having significant electrical length at elevated frequencies.)
- b. Excess solder should be removed so that the step contour between the pin and cable conductor corresponds to the original dimensions. Design has generally taken this step into account and compensated for it in the overall design. A change in dimension by excess solder is in effect a circuit change. Excess solder appears as a shunt capacitance.

14.1.6.2.2 Chemical considerations. Contact of dissimilar metals in a connector can result in electrolytic couples which may promote corrosion through galvanic action. For this reason, the finish of the component parts of a connector must be compatible.

The standard base metal on coaxial connectors is brass. The standard plating is gold.

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14.2 CONNECTORS, MIL-C-39012

14.2 MIL-C-39012.

14.2.1 Introduction. This subsection contains information covering rf coaxial connectors which meet the requirements of military specification MIL-C-39012. There are three series, or sizes, of connectors included in MIL-C-39012, denoted by one or more alphabetical characters: N, TNC, and SMA. Miscellaneous hardware, CW & MX, associated with these connectors is also covered in this specification. MX denotes such things as caps, hoods, and armor clamps. CW designates a cover and is used with caps only. These connectors are used with flexible rf cables and certain other types of coaxial transmission lines.

14.2.1.1 Classification. There are two classes of connectors. A Class I connector is intended to provide superior rf performance at specified frequencies and all rf characteristics are defined. A Class II connector is intended to provide a mechanical connection within an rf circuit and it provides specified rf performance.

14.2.1.2 Categories. MIL-C-39012 connectors have been divided into the following categories.

- Category A - These are connectors which are field replaceable and do not require the use of special tools (standard wrenches, pliers, soldering equipment are not considered special tools).
- Category B - These are not field replaceable and require special crimping tools to assemble. These connectors may be used for original installations, and field replacement is intended to be made using category A or C connectors.
- Category C - These are field replaceable connectors which require a specific crimp tool and cable strip dimensions as designated by the military specification.
- Category D - This is a category of field replaceable connectors in which the military specification defines the following: crimp tool, cable strip dimensions, center contact and crimp ferrule configurations.
- Category E - Semirigid cable connectors - These are field replaceable using a standard cable stripping tool.

14.2.1.3 Characteristics. When classifying connectors into their respective series, there are three main defining characteristics. The first is the size of cable for which they are designed and is classified as small, medium, or large.

The second criterion of classification is the method of coupling or mating. The best method of coupling is by the use of threads. The jacks and receptacles have external body threads and the plugs have internal threads on the coupling nut.

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14.2 CONNECTORS, MIL-C-39012

The third criterion used when classifying connectors is the electrical application, such as high voltage, impedance matched circuits, and dc pulse circuits.

14.2.2 Usual applications. Currently, there are over 30 slash specification sheets covering the series N, TNC, and SMA. Some application considerations for each series are given below.

14.2.2.1 The N series. The N is a threaded coupling connector and is by far the most popular of the medium size connectors. The average cable diameter for the N connector is 0.400 in., but due to its popularity, the diameter ranges from around 0.200 to 0.900 in. for special applications. There are N connectors designed to match 50 or 70 Ω cables. These connectors have a maximum peak voltage rating of 1500 V and a practical frequency limit of 10,000 MHz. They are designed for use with medium size cables and are covered in specification sheets M39012/1 through M39012/5.

14.2.2.2 The TNC series. A TNC connector is a threaded BNC type. This type was developed because the two-ear bayonet locking device of the BNC connector tends to rock during vibration, setting up rf noise in the circuit. The electrical characteristics of the TNC connector are similar to those of the BNC. Specification sheets M39012/26 through M39012/34 cover these connectors.

14.2.2.3 The SMA Series. The SMA is a miniature connector which was originally designed to fill the need for a low VSWR general purpose connector at microwave frequencies. The frequency range specified in MIL-C-39012 for connectors using flexible cable is 0 to 2.4 GHz. Due to its size and inherent ruggedness it is suitable for lower frequency as well. These connectors are covered by M39012/55 through M39012/62.

A new addition of SMA series connectors can be found on specification sheets M39012/79 through M39012/83. This series uses semirigid cable RG402/U and RG405/U. These connectors and cables, when used together, provide better electrical characteristics than the standard flexible cable. They also provide lower attenuation, and no radiation, and permit usage at higher frequencies with good VSWR characteristics. MIL-C-39012 specifies a frequency range of 0 to 18 GHz. However, these connectors have been used at frequencies to 26 GHz in certain applications.

The disadvantage of semirigid cable assemblies is the preparation necessary for using them. Complex drawings defining bends and compound angles are usually necessary to properly route cable and orient the connectors. Assembly is critical due to the solid copper jacket and inner Teflon dielectric problems in termination. A typical problem is cold solder joints between connector and cable which causes electrical intermittencies and weakened terminations. The dimensional stability of the Teflon in the copper jacket is highly susceptible to temperature. The expansion and contraction of Teflon during heating causes many problems in the areas of VSWR and impedance.

There are many experienced cabling houses which have developed processes to minimize these types of problems and provide excellent operating assemblies.

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14.2.2.4 Miscellaneous hardware. Miscellaneous hardware such as covers, shields, clamps, and shorting plugs used with MIL-C-39012 connectors is covered in specification sheet M39012/25.

14.2.3 Physical construction and mechanical characteristics.

14.2.3.1 Physical construction. Figure 3 shows the individual parts of a TNC connector, which is a typical rf coaxial connector covered in MIL-C-39012. A brief discussion of the individual parts is given below.

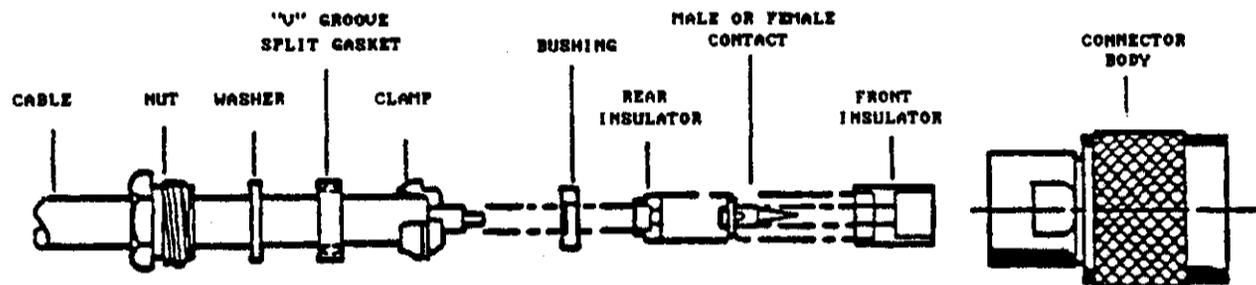


FIGURE 3. TNC connector.

Center contacts. There are two types of center contacts, male and female, which are terminated to the center conductor of the cable. The male contact, sometimes referred to as the male pin, almost always has a solder pocket in one end and is tapered at the other. The female or socket contacts may have a variety of terminations such as a solder pocket, flattened and pierced, or turret but the front end is hollow and generally slotted. The male contact is made from 1/2 hard brass for ease in machining and is plated, usually with gold. The majority of female contacts are beryllium copper. This provides good spring action even after many insertions and withdrawals. Again, the plating is gold. Both male and female contacts may be captivated. The captive contact is made by adding a shoulder of some type on the contact and then physically holding it into the connector. It is usually held in place by putting it between two insulators which are in turn held stationary by a clamp nut or a staking operation.

The crimp type contact is deformed on assembly, causing a discontinuity. However, by designing the inner contact to compensate for these crimping changes, excellent performance is possible and many new designs feature this.

Insulator. The dielectric of the connector is referred to as the insulator. The insulator varies in configuration depending upon the connector style and type. The materials also vary with the applications. The major insulation materials are polystyrene and Teflon.

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Outer contact. This part of the connector is electrically connected with the outer shield of the cable and serves to carry a signal, to act as a shield, or as a grounding member of the circuit. In the case of jacks and receptacles, the body of the connector is the outer contact. The plug may have an outer contact and a coupling nut or just a coupling nut which acts as the outer contact. The term "outer contact" is used only when referring to the tinned portion of the body and is generally made out of nickel-plated beryllium copper because of its good spring action and electrical characteristics.

Coupling nut. The coupling nut is that portion of the connector that mechanically joins two connectors. The coupling nut material is usually 1/2 hard brass with nickel plating, or corrosion resisting steel that has been passivated.

Connector body. The bodies of coaxial connectors may utilize the same material and plating, or finish as the coupling nut. Body configurations depend on the type of connector and will be covered under the type description.

Cable retention methods. There are three basic methods of attaching the cable to the connector: soldering, clamping, and crimping. Soldering of center contacts was discussed previously. In some of the earlier UHF series connectors, the braid was soldered to the connector. The clamping method of attachment requires the use of additional piece parts, the braid clamp and "V" groove gasket. The clamp is usually made of brass or nickel-plated phosphor bronze. The gasket is rubber. The washer is usually brass or phosphor bronze and nickel plated. The last part is the clamp nut which, when tightened into the body of the connector, supplies the force which holds the cable into the connector. As the clamp nut is tightened down, the "V" groove gasket splits, allowing metal to metal contact in the retention mechanism, and forms a seal between the cable jacket and the connector. In the crimping method, the braid clamp, gasket, washer, and clamp nut are replaced by a ferrule clamp nut assembly or ferrule which is an extension of the body. The cable dielectric and center conductor are put inside the ferrule and the cable braid and compressed by means of a crimping tool. The inner female assembly is of nickel-plated brass but the outer ferrule must be of a softer copper alloy because it must be deformed. The biggest advantage of the crimping method of assembly is that it is a much easier method than clamping. Also, the cable stripping dimensions are not as critical. There is no combining of the braid nor is there a problem with the tightening torque necessary to obtain satisfactory cable retention. Its main disadvantage of crimping is the need for special tools.

14.2.3.2 Typical mating configuration. Figures 4 through 8 show typical SMA and N series connector configurations.

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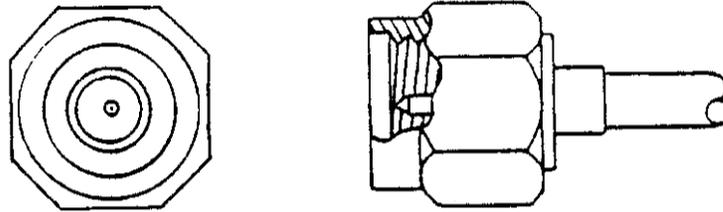


FIGURE 4. Typical SMA plug.

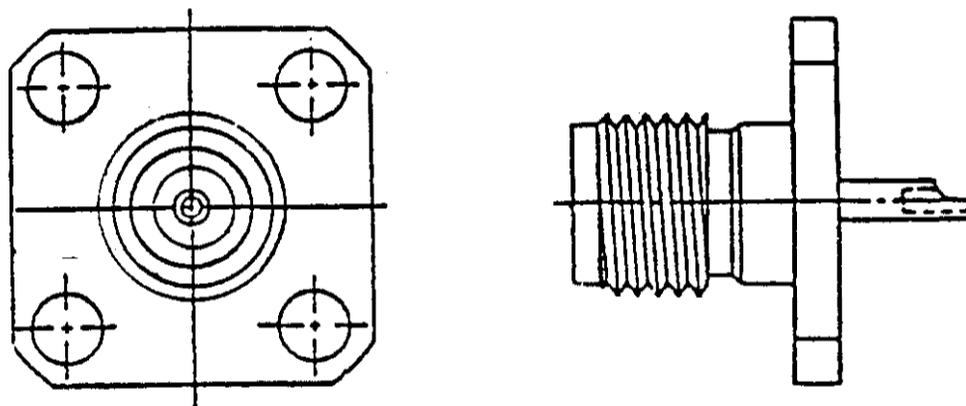


FIGURE 5. Typical SMA flange-mount receptacle.

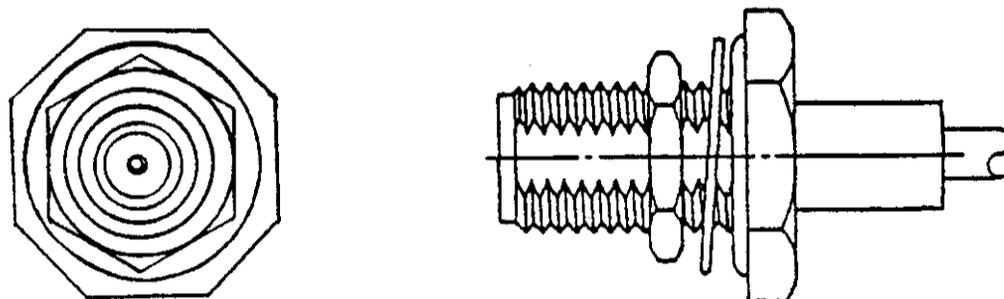


FIGURE 6. Typical SMA type bulkhead-mount jack.

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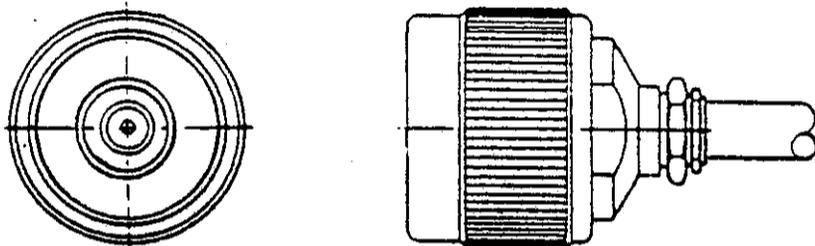


FIGURE 7. Typical N-type plug.

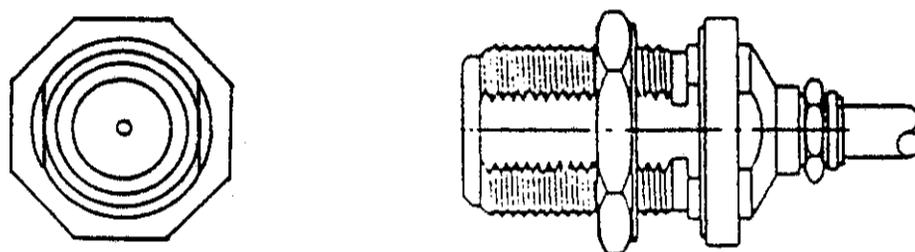
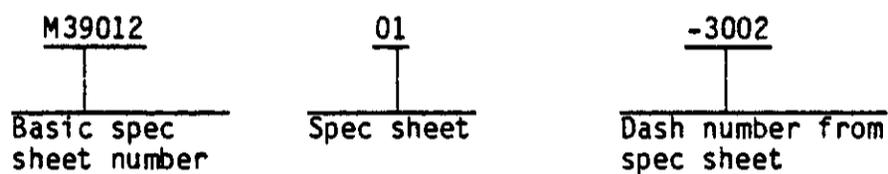


FIGURE 8. Typical N-type bulkhead-mount jack.

14.2.4 Military designation. The part number consists of the letter M followed by the basic specification sheet number and a sequentially assigned dash number.



The first digit of the dash number denotes material

- 0 - Brass
- 1 - Phosphor bronze
- 2 - Aluminum
- 3 - Corrosion resistant steel
- 4 - Beryllium copper

The example above represents a series N plug made of corrosion-resistant steel.

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14.2.5 Electrical characteristics.

14.2.5.1 Impedance. Coaxial connectors are designed to keep a constant impedance throughout the connector. For maximum energy transfer, the connector's nominal impedance should be the same as the characteristic impedance of the cable to be used with the connector. Connectors covered in MIL-C-39012 have a nominal impedance of 50 Ω , although N connectors may be obtained to match 70 Ω cables.

14.2.5.2 Voltage rating. Rf connector design involves compromises where one desired characteristic is sacrificed to some extent to obtain another characteristic. This is true regarding impedance matching and high voltage characteristics. These two parameters are not compatible. To obtain a high voltage rating, especially at the junction of the cable core and connector insulator, requires a long overlap of cable core, which in turn presents an inductive discontinuity. This is partially compensated for by using an adjacent section of low impedance line, generally in the form of an oversize center contact.

14.2.5.3 Frequency range. At the lowest frequencies (dc, for example) cable connections consisting of simple solder joints to both conductors are sufficient, if mechanically firm.

As application frequency progresses into the low megahertz range, such connections allow rf leakage and it becomes necessary to provide contact to the center conductor (as before) and 360 degree contact to the outer conductor to completely contain the conducted electromagnetic fields between the two conductors. The characteristic impedance of the section of line represented by the inner and outer diameters of the connector is generally not important. The familiar "UHF" series of connectors is an example of this frequency range.

When application frequency reaches the hundreds of megahertz, it is important that the characteristic impedance of the connector be the same as that of the cable. Also, any physical discontinuities (e.g., connector pin diameter differing from the cable inner conductor diameter) must be held to a minimum. These discontinuities behave as shunt capacitors or series inductances.

The adverse effect of these reactive discontinuities increases with application frequency. Therefore, to maintain a given level of performance, the physical size of the discontinuities underlying them must be kept smaller and smaller as frequency is raised. It is not always possible to avoid all discontinuities and, at the same time, maintain a sound mechanical joint. The frequency range of MIL-C-39012 connectors is given in Figure 1.

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14.2.5.4 Insulation resistance. This is the resistance offered by the insulating members of a component part to an impressed dc voltage; it tends to produce a leakage current through or on the surface of these members. Insulation resistance is an important parameter in the design of high impedance circuits. Low values of insulation resistance are indicative of large leakage currents which can disturb the operation of circuits intended to be isolated, for example, feedback loops. Excessive leakage currents can contribute to insulation deterioration as a result of heating and dc electrolysis. Some factors affecting insulation resistance are temperature, humidity, and residual charges.

14.2.5.5 Contact resistance. The millivolt drop between the braid and outer conductor at the point of contact, between outer contacts and between center contacts, is measured with a current of 1 A passing through the contacts under test. At this current, the contact resistance in milliohms is numerically equal to the measured millivolt drop.

14.2.5.6 Dielectric withstanding voltage. (Also called hipot, voltage breakdown, and dielectric strength). To obtain this parameter, a voltage higher than the rated voltage is applied for a specified time between insulated portions of a component part or between insulated portions and ground. This tests the ability of the component part to operate safely at its rated voltage and withstand momentary over-voltages. This test is not intended to cause insulation breakdown or for corona detection; rather it serves to determine whether or not insulating materials and spacings in the component part are adequate. Some factors affecting the dielectric strength of a material are: temperature, pressure, humidity, rate of amplification of test voltage, time duration of test voltage, shape of test specimen, and form of electrodes.

14.2.5.7 Rf high potential withstanding voltage. This test is similar to the dielectric withstanding voltage test. However, the frequency of the applied voltage is on the order of 5 MHz versus 60 Hz used in the dielectric withstanding voltage test. The test is performed to determine the ability of a cabled, mated pair of connectors to withstand high rf voltages without excessive leakages or electrical breakdown.

14.2.5.8 Voltage standing wave ratio (VSWR). Impedance mismatch (or input impedance versus output impedance) in a transmission line causes reflected power which will interfere with the transmitted power in such a way as to set up standing waves on the line. These standing waves will have maximums and minimums at one-quarter wavelength intervals. The ratio of maximum to minimum of the standing wave voltages along the transmission line is called the voltage standing wave ratio (VSWR). This ratio is a figure of merit for the matching of input to output impedance of a connector, and a VSWR of 1 indicates no reflected power. In rf coaxial connectors, VSWR varies with the frequency and over a broad frequency range. The VSWR will be greater at the higher frequencies.

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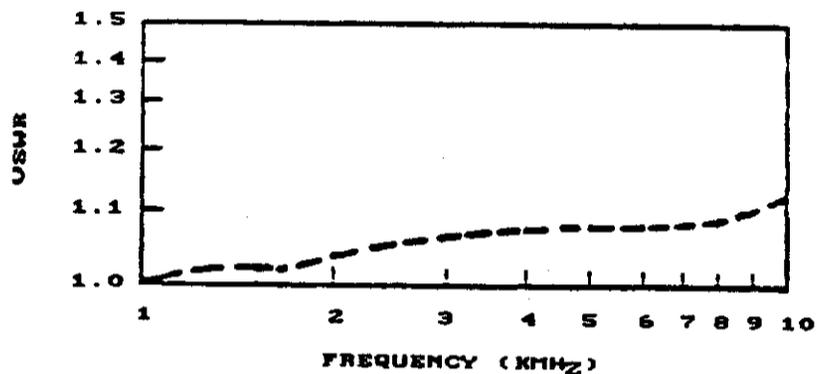


FIGURE 9. Typical VSWR curve for series N connector.

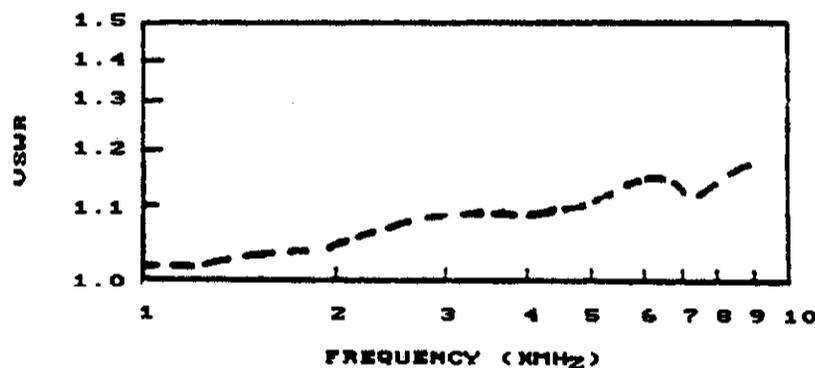


FIGURE 10. Typical VSWR curve for serial TNC connector.

14.2.5.9 Corona level. Corona is the result of ionization of air. A high corona level can cause a sustained electrical discharge which can damage the connector and cable assembly. Corona tests can be used for the detection of air pockets in the insulation or dielectric of connector and cable assemblies. The presence of corona is detected by testing at a specified barometric pressure, usually 70,000 ft, and a specified voltage. The connectors are cabled and mated for this test.

Typical VSWR curves for series N and TNC connectors from a selected vendor's catalog are shown in Figures 9 and 10 respectively, for mated plugs and jacks using medium size 50 Ω cable.

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14.2.5.10 Rf leakage. The word leakage is used to describe both the loss of internal energy (rf) from a microwave circuit and the entrance of energy into a microwave circuit. Errors due to leakage can sometimes be 1 dB or greater. Usually leakage is due to poor mechanical conditions involving damaged or dirty parts or poor assembly. It can also result from poor design.

14.2.5.11 Rf insertion loss. Insertion loss is the ratio of power delivered to a matched load by a matched generator before and after the insertion of a component (connector) into the line. It is a combination of two losses: mismatch loss (reflective) and attenuation (dissipative). Mismatch loss is the ratio of ratio of power that would be absorbed by the device if it were perfectly matched to that of the actual power absorbed by the device with its mismatch in impedance. Attenuation is the ratio of power into a component to the power out under matched conditions and represents the actual power dissipated within the component. Where a component is matched perfectly into the line and load, this mismatch loss is zero and the insertion loss is the same as the attenuation.

Refer to Table II for typical values of the previously discussed parameters for the various series of MIL-C-39012 connectors.

14.2.6 Mechanical requirements. Connectors have their mechanical requirements itemized on the appropriate sheet of MIL-C-39012. Among the mechanical aspects to be considered are: material, finishes, dissimilar metal restrictions, center contacts, allowed displacement, engage and disengage force, coupling tightening torque, mating characteristics, and permeability of nonmagnetic materials.

14.2.7 Environmental considerations. There are no extraordinary environmental considerations for these connectors.

14.2.8 Reliability considerations. Coaxial connector failures are usually mechanical in nature. Generally, they can be attributed to poor workmanship during assembly of the connector to the cable. Poor soldering techniques of the solder connections are common failure modes. Cable stripping dimensions should be made with care. Poor workmanship can cause degradation of electrical parameters, such as VSWR, rf leakage, and insertion loss. It can also result in a low cable retention force and a possible separation of cable and connector. In high voltage connectors, corona at reduced barometric pressure can result from air pockets in the connector dielectric, due to construction or poor assembly techniques. Pressurized connectors have the additional problem of defective seals. Rough handling, rather than construction, would probably be the most common cause of leaking seals.

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TABLE II. Typical electrical characteristic values

Series	Minimum insulation resistance (megohm)	Millivolt drop-contact resistance (millivolts, max)		Dielectric withstanding voltage (Vrms @ sea level, min)	Rf High potential withstanding voltage (Vrms @ 5 MHz, min)
		Center contact	Outer contact		
N	5,000	1.0	0.20	2,500	1,500
TNC	5,000	2.1	0.20	1,500	1,000
SMA	200	4.0	2.0	500 <u>2/</u>	335 <u>2/</u>

TABLE II. Typical electrical characteristic values (Continued)

Series	VSWR (500 Hz to 12.4 GHz, max)	Corona level (@ 70 K Ft, min)	RF leakage (2-3 GHz, dB, min)	Insertion loss (@ 10 GHz, dB, min)	Voltage rating (Vrms max. work. volt.)	Frequency range (GHz)
N	1.30	500	-90	0.15	1,000	0-11
TNC	1.30	250	-60	0.20 <u>1/</u>	500	0-11
SMA	1.20 <u>3/</u>	125 <u>2/</u>	-60	0.60 <u>4/</u>	170	0-12.4

- 1/ 500 Hz to 5 GHz
2/ Using RG178 cable
3/ 500 Hz to 12.4 GHz
4/ At 6 GHz

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14.2 CONNECTORS, MIL-C-39012

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15.1 PROTECTIVE DEVICES, GENERAL

15. PROTECTIVE DEVICES

15.1 General.

15.1.1 Introduction. In designing circuit protection, the whole electrical system--power source, transmission path and individual components--must be considered. In addition to minimizing damage to a malfunctioning unit, the fuse or circuit breaker must also protect the rest of the system from any fault that may occur. When one element within the system fails, the protective device should isolate it so that other portions of the system continue to function normally.

This section will discuss protective devices which are included in MIL-STD-975 NASA Standard Electrical, Electronic, and Electromechanical (EEE) Parts List as well as thermal circuit breakers that are not included.

15.1.1.1 Applicable military specifications.

MIL-F-23419	Fuses, Instrument Type, General Specification
MIL-C-5809	General Specification for Trip-Free Aircraft Circuit Breakers
MIL-C-39019	General Specification for Magnetic, Low-Power, Sealed Trip-Free, Circuit Breakers.

Only MIL-F-23419 and MIL-C-39019 devices are included in MIL-STD-975.

15.1.2 General definitions. The following is a list of terms commonly used with circuit protective devices.

Adjusted circuit or bolted-fault level. The current in a circuit measured under short circuit conditions with the leads normally connected to the circuit breaker bolted together.

Ambient temperature compensation. A method used in protective devices to compensate for the effects of ambient temperatures so as to prevent a change in calibration.

Arc extinction. Use of special methods to control contact arcing in circuit breakers.

Circuit breaker. An automatic device which, under abnormal conditions, will open a current-carrying circuit without damaging itself.

Circuit breaker cascade system. A system wherein the protective devices are arranged in order of ratings such that those in series will coordinate and provide the required protection.

Circuit breaker, nontrip-free. A circuit breaker that can be kept closed by manual override action while a tripping condition persists.

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15.1 PROTECTIVE DEVICES, GENERAL

Circuit protection. Automatic protection to minimize the danger of fire or smoke as well as the disturbance to the rest of the system that may result from electrical faults or prolonged electrical overloads.

Coordination. Arrangement of a lower-rated breaker in series to trip before the higher-rated one trips.

Crowbar. An action that effectively creates a high overload on the actuating member of the protective device. This crowbar action may be triggered by a slight increase in current or voltage.

Current-limiting fuse. A protective device that prevents a dangerous short circuit current by opening the circuit before the development of the peak available current.

Fuse. A protective device with a circuit-opening fusible member that is destroyed by the passage of overcurrent.

Instantaneous. A circuit breaker that trips above a predetermined value of current without any purposely delayed action.

Joined actuator. A multipole breaker that trips all poles when one pole trips. When the faulted pole is trip-free (will not close the contact), the other poles may be kept in position by the restraining actuator.

Let-thru current. The current that actually passes through the breaker under short-circuit conditions.

Manual switching. A circuit breaker feature permitting manual opening and closing of the circuit.

Rupture or interrupting capacity. The maximum current that a protective device will interrupt. It is specified as the number of interruptions in amperes without change in calibration or failure of dielectric strength.

Self-wiping contacts. A switch or relay contact designed to move laterally with a wiping motion when engaging with or disengaging from a mating contact. This feature assures low contact resistance, which is particularly important on low-current circuit breakers.

Short time limits. Values of minimum and maximum trip time measured at various percentages of overload.

Time constant. A measure of the response of a system expressed as the time required to reach 63.2 percent of the total change in value.

Trip-free. A safety device construction in which the contact arm is independent of the operating handle or mechanism, making it impossible to manually hold the contacts closed during an overcurrent or short circuit fault.

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15.1 PROTECTIVE DEVICES, GENERAL

Trip-free breaker. A breaker so designed that it will not maintain the circuit closed when carrying overload currents regardless of the restraint placed on the actuator. All poles of a multiple breaker should trip free on a single-pole fault or overload.

Trip indication. The means of indicating that the circuit breaker has tripped or is in open position.

Ultimate trip current. The smallest value of current that will cause tripping of the circuit breaker under a given set of ambient conditions.

Ultimate trip limits. The specified limits for ultimate trip currents: maximum ultimate trip current and minimum ultimate trip current. At the maximum specified ultimate trip current the breaker will open within the specified time, and at the minimum specified ultimate trip current the breaker will not open.

15.1.3 General device characteristics. The general characteristics of fuses and circuit breakers are discussed below. Both fuses and circuit breakers are available for ac or dc applications. Some circuit breakers must be selected for either ac or dc application (see the discussion below).

15.1.3.1 Fuses. A fuse is a protective device that melts and breaks the circuit when the current exceeds the rated value. Its purpose is to protect the other elements of the circuit from a possibly damaging overload.

Fuses are generally a glass-bodied cartridge with nickel-plated brass caps. High-amperage fuses are made of a punched zinc alloy element. Low-amperage fuses are made with filament wires of various materials such as copper, platinum, or alloy.

15.1.3.2 Circuit breakers. There are, essentially, two types of circuit breakers: thermal breakers and magnetic breakers. (Only magnetic breakers are included in MIL-STD-975). Both provide overcurrent protection; the difference lies in how they perform this function. Following is a brief description of the two types.

Thermal breakers. Thermal breakers convert current into heat, which operates the tripping mechanism. Unless compensated, thermal breakers tend to be sensitive to ambient temperature. Thermal breakers have an inherently slow response to current variations and therefore are not generally frequency-sensitive or prone to nuisance tripping from transients. However, they are sensitive to shock and vibration. The most common form of thermal breaker utilizes a bimetallic heat sensing element.

One type of thermal breaker is a hot wire breaker in which the expansion and contraction of a hot wire element operates the tripping mechanism. Because the hot wire has less thermal lag than the bimetallic type, it offers faster response time.

15.1 PROTECTIVE DEVICES, GENERAL

Magnetic breakers. Magnetic breakers are strictly current devices and can be quite fast. Many magnetic breakers incorporate a hydraulic dashpot that provides an inverse time delay on values of overload below the instantaneous trip point. Magnetic breakers supplied without the dashpot are referred to as "instantaneous." The effect of mechanical vibration is a function of the particular breaker design. Different breakers are needed for dc, 60 Hz, or 400 Hz. Tripping varies with frequency but can be compensated by proper breaker calibration. The tripping coil is frequently actuated by a circuit other than the one that is protected. This arrangement allows use of a magnetic breaker in combination "control--protection" circuits.

15.1.4 General parameter information.

15.1.4.1 Fuses. Fuses are the safety valves of electrical circuits; it is important that they operate or "blow" before damage occurs in the equipment or the wiring being protected. Conversely, fuses must not blow too easily and cause open circuits when the equipment is operating normally.

15.1.4.2 Circuit breakers. Thermal, compensated thermal, and thermal-magnetic circuit breakers may be used on either ac or dc because their tripping properties are thermally dependent. However, hydraulic-magnetic circuit breakers are dependent on magnetic pulses and must therefore be used on the electrical frequency for which they were designed.

15.1.5 General guides and charts. The specific military specifications must be used in the selection of specific fuses and circuit breakers.

15.1.6 General reliability considerations.

15.1.6.1 Fuses. When the fuse is used in a circuit other than the test circuit, its rating can change. It is the circuit designer's responsibility to determine that the fuse is the proper one for the application.

Most small fuses are inherently able to withstand most environmental conditions, the most severe of which are vibration and shock. The smaller the fuse, the more resistant it is to mechanical shock and vibration because the fuse link is short and does not easily resonate.

15.1.6.2 Circuit breakers. Circuit breakers are subject to both electrical and mechanical failure. The most significant factor in circuit breaker reliability is proper selection of a suitable type for the application.

Two basic types of circuit breakers are commonly used: magnetic and thermal. The magnetic type is used in airborne equipment and similar environments where wide excursions of temperature may occur. The thermal type should be limited to environments that provide relatively stable and low temperatures (below 100 °C), as the current-carrying capabilities of the thermal sensing element are highly sensitive to temperature variations.

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Hermetically sealed devices should be used where it is practical to eliminate failures caused by external contamination.

Snap action switching of contacts should be designed to minimize arcing time and should have a wiping action.

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**15.2 PROTECTIVE DEVICES,
CIRCUIT BREAKERS**

15.2 Circuit breakers.

15.2.1 Introduction. A circuit breaker is a device for closing or interrupting a circuit between separable contacts under normal and abnormal conditions. Normal refers to interruption of currents within the continuous current rating of the circuit breakers. Abnormal refers to interruption of currents exceeding the continuous current rating such as short circuits. Ordinarily, circuit breakers are required to operate relatively infrequently although some classes of breakers are suitable for frequent operation. Only magnetic circuit breakers are included in MIL-STD-975.

15.2.1.1 Applicable military specifications.

MIL-C-5809 General Specification for Trip-Free
Aircraft Circuit Breakers

MIL-C-39019 General Specification for Magnetic Low-
Power, Trip-Free Sealed Circuit Breakers.

15.2.1.2 Circuit breaker types. Four basic kinds of circuit breakers are discussed in this section:

- a. Thermal
- b. Magnetic (included in MIL-STD-975)
- c. Thermal-magnetic
- d. Compensated thermal and thermal-magnetic.

Mechanical breakers, both thermal and magnetic, require an appreciable time to operate. Magnetic types are the fastest. For a total short circuit, the mechanical mechanism of a fast magnetic breaker will act within three or four milliseconds. This is not fast enough for certain kinds of diodes and silicon controlled rectifiers with heat sinks that do conduct heat away with sufficient speed. However, magnetic mechanical breakers do operate rapidly enough for most protection, at least when some limit to current exists in the circuit. Figure 1 illustrates the time-to-trip of a typical magnetic breaker, up to 10 times rated current. The band on the curve indicates that the breakers will not trip below the lower line of the band, may trip anywhere inside the band, and will trip above the band.

15.2.1.3 Thermal breakers. Thermal breakers use heating elements that activate bimetallic devices to trip out a contact. In effect, the bimetallic element pulls the trigger of a spring loaded switch, which then flies open.

Thermal circuit breakers are best suited to protect wire, because the thermal element within the breaker is a reasonable analog of the protected wire.

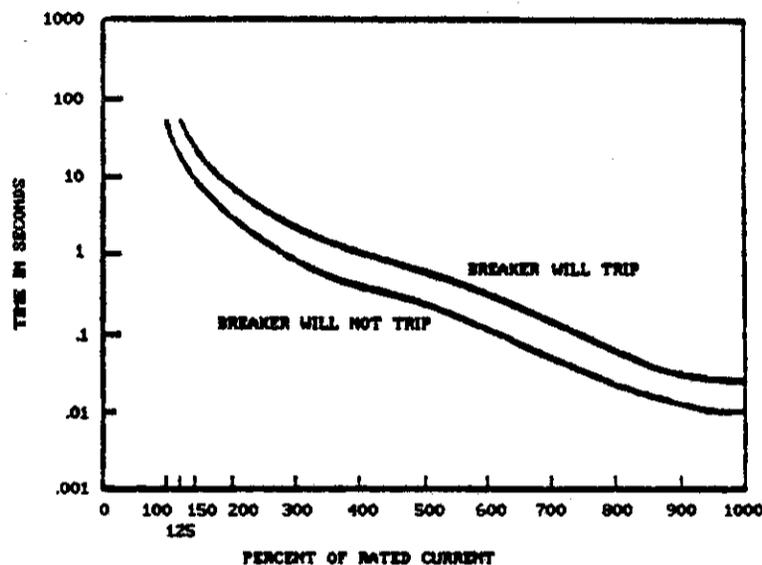
15.2 PROTECTIVE DEVICES,
CIRCUIT BREAKERS

FIGURE 1. Trip-time characteristics of a typical magnetic breaker.

Selecting the correct thermal breaker is more complex than simply matching the breaker rating with the wire rating. One must also consider the ambient operating temperature, the allowable voltage drop, and the heat sink provided. Although thermal breakers are necessarily temperature sensitive, proper design permits some compensation for ambient temperature change.

Trip action is obtained with bimetals and trimetals. The low-expansion side may be Invar, the center may be copper for low resistivity or nickel for high resistivity. Metals used in the high expansion side vary considerably.

The speed of a thermal breaker varies directly with temperature and with the square of the current.

15.2.1.4 Hydraulic-magnetic breakers. Most circuits are subject to momentary currents that exceed the normal continuous current that can be carried safely by the wiring or the equipment load. A motor, for example, draws high current when power is first applied.

As the motor approaches running speed, the current requirement quickly drops to normal. Because of the comparatively short duration of the high current, most circuitry and equipment can safely tolerate it. Therefore, it is not desirable to have circuit interruptions for these transient overloads, but it is necessary to interrupt prolonged or heavy overcurrents.

The hydraulic-magnet circuit breaker provides for both situations; it will interrupt a circuit instantaneously at 1000 percent rated current, and it will provide an inverse time delay to allow for normal inrush surges and tolerable overloads.

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**15.2 PROTECTIVE DEVICES,
CIRCUIT BREAKERS**

Time delay is provided by the action of the fluid-damped movable core in the magnetic element. Overall delay characteristics are determined by several design variables, the most important being the viscosity of the damping fluid. Through adjustment of these variables, virtually any time-delay curve (trip time versus percent load) can be obtained.

Properly specified and applied, time delay never results in loosening of the protection standards. It permits closer tolerances because it can be tailored to the operating characteristics, both starting and running, for the circuit to be protected. With time delay there is no need for overrating (with consequent loss of protection against small, sustained over-currents) to avoid nuisance power interruptions.

There are some applications where only extremely small and very brief current changes can be tolerated, and where time delay is not desirable. For such applications, breakers are available that are designed to trip instantaneously (i.e., without any deliberately imposed delay) above a predetermined current level.

In the time-delay range between the minimum and instantaneous trip-points, there is a definite and desirable ambient temperature effect. With a higher ambient temperature, it is still necessary to carry the rated load, but overloads cannot be tolerated for as long a period. With lower ambient temperatures, overloads can be more prolonged without damage to the equipment. Because fluid viscosity is an inverse function of temperature, the time delay is self-adjusting. As temperatures drop, the fluid becomes more viscous, lengthening the delay period and providing extra time for starting up cold equipment with safety. As the temperature rises, viscosity (and the time delay) decreases, giving a safe margin of protection at higher ambients.

This self-adjusting time delay does not affect the current rating of the breaker.

With the instantaneous trip point establishing the maximum current point on the time delay curve, it is necessary to establish the minimum point at which the circuit breaker will trip.

With the hydraulic-magnetic breaker the minimum trip point is not affected by ambient temperature, and derating is not required.

15.2.1.5 Thermal-magnetic breakers. These are similar to thermal breakers except that a magnetic feature has been added to give an instantaneous tripping point when current reaches a certain level. This provides the normal time delay of a thermal breaker and the high instantaneous overload protection of a magnetic breaker.

15.2.1.6 Compensated thermal and thermal-magnetic breakers. These are similar to thermal and thermal-magnetic breakers, except that an additional bimetallic element is used with the overload element. As the ambient temperature increases, the additional bimetallic element compensates for the temperature change.

**15.2 PROTECTIVE DEVICES,
CIRCUIT BREAKERS**

15.2.2 Usual applications. A circuit breaker, regardless of its application, must accomplish four basic tasks:

- a. When closed, it should be an ideal conductor.
- b. When open, it should be an ideal insulator.
- c. When closed, it must be able to interrupt the assigned current promptly without causing dangerous overvoltages.
- d. When open it must be able to close promptly, possibly under short circuit conditions, without being damaged by contact welding, etc.

Often automatic reclosing of circuit breakers is required. In about 80 percent of the cases, by the time a circuit interruption takes place the cause no longer exists and the breaker closes again with no problem. About 20 percent of the causes persist and the circuit breakers may have to interrupt another short circuit immediately after reclosing.

A circuit breaker must have sufficient short circuit rupture capacity under all conditions to isolate the fault, even if directly shorted at the load terminal of the breaker.

Because circuit breakers have trip-point tolerance, this must be considered in their selection; the individual specification sheet must be examined because breakers do not trip at just above rated value.

15.2.2.1 Trip-free versus nontrip-free construction. In most applications, trip-free construction is required. With this construction, the contact arm is independent of the manual operating handle while a fault exists. It is impossible to hold the contacts manually closed against an overload or short circuit.

There are applications, primarily in aircraft operation, where a nontrip-free construction is desirable. These are cases where the function performed by the equipment is more important than the equipment itself; in these cases, non-trip-free construction permits the contacts to be held closed manually against the fault.

The most common internal circuit arrangements and representative applications are presented here. Many other forms are not illustrated here including several coils in a single breaker, additive or bucking magnetic fields, and one design that even protects against both overloads and reverse current.

15.2.2.2 Series-trip. Series trip is the standard circuit breaker construction. Coil and contacts are in series with the line and load terminals. Overcurrent sensing and circuit interruption are therefore in the protected circuit itself. This is the conventional circuit breaker arrangement used as a main switch and short-circuit protection for supply voltage wiring, or for overload protection of equipment or electronic components such as filament and plate supply transformers, motors and operating coils of solenoids.

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15.2.2.3 Shunt-trip. Shunt trip permits tripping from circuit-closing contacts in remote control, or safety devices responsive to changes in temperature, pressure, air flow, or any other measurable function. Shunt-trip breakers utilize line voltage; relay trip breakers (15.2.2.4) can also be tripped from remote contacts, but they are usually employed when the coil and contacts must be in separate circuits using different voltages or types of current.

A shunt-trip coil does not provide a time delay unless specified. Designed for noncontinuous duty, it must be de-energized when the breaker contacts open. Within limits, continuous-duty coils can be furnished. The combined current through the load and shunt-trip terminals must not exceed contact rating of breaker contact.

15.2.2.4 Relay trip. Relay trip provides a separate control circuit that may be actuated from a remotely located control or safety device. Electrical isolation of the coil from the contacts permits the use of a different current from that of the lead circuit.

Voltage-sensing relay trip coils are normally supplied without time delay and are for noncontinuous duty; i.e., the coil must be de-energized when the contacts open. Time-delay construction is also available and, within limitations, continuous-duty coils may be furnished.

Current-sensing coils are normally for continuous duty, and are furnished with a time-delay characteristic. Nontime-delay coils are also available.

When selecting relay trip construction, always specify the current and voltage values for the coil and contacts separately.

15.2.2.5 Auxiliary switches. Auxiliary contacts are furnished as miniature, snap-action switches mounted on the back of a circuit breaker. They are mechanically coupled to the breaker's switching mechanism but electrically isolated from it. When it is desirable to relate breaker operation to the control of indicators, alarms, lights, fans, and similar circuits, auxiliary switches offer a convenient and dependable solution.

An auxiliary switch can be supplied on each pole of a multipole breaker. The only limitation is that the pole must be of series-trip or switch-only construction to accommodate the switch. Single-pole, double throw (SPDT) contacts furnish a choice of open or closed operation, regardless of circuit breaker contact position. As shown, the normal condition of the auxiliary switch (N.O.: contacts open, N.C.: contacts closed) is with the breaker in the "off" position.

15.2.2.6 Dual rating. Dual rating permits the use of one circuit breaker with two ratings to protect equipment designed to operate at two different current levels. Breakers have two load terminals, each with a different rating. The ratings are usually provided in a 2-to-1 ratio; however, ratios up to 4-to-1 can be provided. Minimum dual ratings are 1 and 2 amperes; maximum 25 and 50 amperes.

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Breakers with dual-rating construction can also be used with equipment designed to operate on two different voltages, such as 6/12 V dc or 110/220 V ac. For example, a dual rating of 10 A at 110 V and 5 A at 220 V can be provided.

15.2.2.7 Calibrating-tap. A calibrating tap permits two loads to be controlled by a single breaker, but trips in response to overloads in the main circuit only. Though it resembles a shunt-trip schematically, calibrating-tap construction uses current-sensing coils and, like series-trip, can be furnished with time-delay characteristics. Auxiliary loads connected to the calibrating-tap terminal are switched on and off with the main load, but they cannot trip the breaker. The combined main and auxiliary loads must not exceed the breaker's contact rating.

This circuit is called calibrating-tap because the breaker's rating and trip points can be raised by shunting the coil with a resistor. This function is limited to breakers with ratings of one ampere, and the maximum practical increase is four to five times the breaker's rating.

15.2.2.8 No-voltage-trip and remote-trip. Breakers are available with a special back-mounted electromechanical relay that is adjusted to provide either a no-voltage-trip or a remote trip function. Breakers furnished for no-voltage trip will trip instantly in response to a loss of voltage in a normally energized circuit. The lost voltage can be the breaker's own line voltage, or an ac voltage from 120 V to 480 V. Once the relay is de-energized, the tripped breaker cannot physically be reset until the relay voltage is restored.

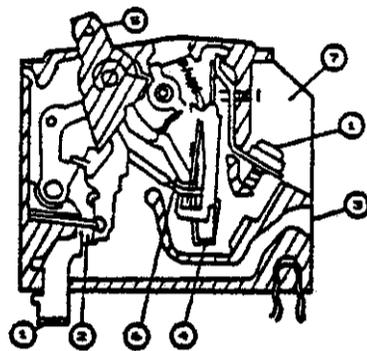
Breakers equipped for remote tripping will trip instantly in response to the closing of remotely located control or alarm contacts. The breaker cannot be reset until the contacts open.

15.2.3 Physical construction and mechanical characteristics. As noted in the previous discussion, two basic means are used to obtain circuit interruption with a circuit breaker: thermal and magnetic. Our discussion here will be limited to a description of these two basic devices.

Thermal breakers use a bimetallic element which deforms because of the heat generated by current going through it or an auxiliary heating element; this triggers a spring-loaded switch which opens. An example of a thermal device is shown in Figure 2.

Magnetic circuit breakers depend on changes in magnetic flux caused by load current changes in a solenoid coil. The sensing and tripping functions are performed by separate elements--the solenoid coil and a mechanical latch. Since this is an almost instantaneous tripping action, time delays are usually built in by the use of hydraulic damping. An example of a typical magnetic circuit breaker is shown in Figure 3.

**15.2 PROTECTIVE DEVICES,
CIRCUIT BREAKERS**



- 1. TERMINALS
- 2. CONTACTS
- 3. BLOWOUTS UENT
- 4. BIMETAL
- 5. HANDLE
- 6. LATCH
- 7. CASE

FIGURE 2. Outline of a typical thermal breaker.

As long as the current flowing through the unit remains below 100 percent of the rated current of the unit, the mechanism will not trip and the contacts will remain closed as shown in Figure 3. Under these conditions the electrical circuit can be opened and closed by moving the toggle handle on and off.

If the current is increased to between 100 percent and 125 percent of the rated current of the unit, the magnetic flux generated in coil 5 is sufficient to move the delay core 3 against spring 11 to a position where it comes to rest against pole piece 12 as shown in Figure 3.

- 2 Armature
- 3 Delay core
- 4 Terminal
- 5 Coil
- 6 Contact bar
- 7 Contact
- 8 Contact
- 9 Terminal
- 10 Toggle
- 11 Spring
- 12 Pole piece

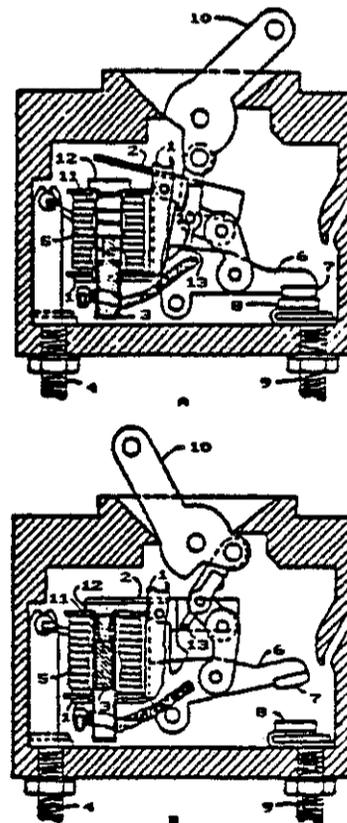


FIGURE 3. Operating mechanism of a typical magnetic circuit breaker.

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CIRCUIT BREAKERS

15.2.4 Military designation.

MIL-C-5809. The military part number is on MS drawing which refers to MIL-C-5809. The designation is:

M25304 - XX
| |
Basic Dash
drawing number

MIL-C-39019. This device is included in MIL-STD-975. The military designation is as follows:

M39019 - /XX - XXX
| | |
Military Slash Dash
specification sheet number

15.2.5 Electrical characteristics. Refer to the applicable military specification and slash sheet for details of performance. In general, magnetic type circuit breakers are rated from 0.05 ampere current capacity to 20 amperes with a trip time either "fast" or "slow." Fast trip is less than 1 second at 200% of rated current at 25 °C. Slow trip is less than 9 seconds for the same conditions.

15.2.6 Environmental considerations. Circuit breakers conforming to either MIL-C-5809 or MIL-C-39019 meet the environmental requirements of most military applications. The environmental requirements of both specifications are quite similar except for the following:

- a. MIL-C-5809 circuit breakers are required to withstand a 50-G, 11 ms half-sine shock, whereas MIL-C-39019 circuit breakers are required to withstand a 100-G, 6 ms sawtooth shock.
- b. MIL-C-39019 circuit breakers are sealed devices and have a thermal shock requirement over a temperature range of -65 to +125 °C whereas MIL-C-5809 has no thermal shock requirements.

15.2.7 Reliability considerations. Consult paragraph 15.1.7, for general reliability considerations of circuit breakers.

15.3 PROTECTIVE DEVICES, FUSES

15.3 Fuses.

15.3.1 Introduction. The fuses discussed in this section include only those normally used in electronic equipment. The current ratings of these fuses range up to 15 A. The voltage ratings range up to 125 V.

A fuse is generally considered the weakest link in the circuit. This is not always true and can be understood by considering the normal functions of the fuse. These functions take two forms: equipment protection and fault isolation.

When protecting equipment, the fuse is selected to open before any other component is damaged or becomes a menace to safety.

When used for isolation, the fuse must clear the circuit after some component or wire has had an electrical fault that has been damaging to itself. The fuse must clear the circuit and isolate the faulted portion from the rest of the system so that the latter can continue to operate. The fuse rating is selected so that it is not the weakest link. It cannot prevent a component from failing; it protects the remainder of the system.

15.3.1.1 Applicable military specifications.

MIL-F-23419 Fuses, Instrument Type, General Specification.

15.3.2 Usual applications. Fuses are used to protect circuits and equipment from current overload.

The following questions should be answered when deciding on the proper fuse:

- a. What is the normal operating current?
- b. What is the abnormal current at which the fuse is required to open the circuit?
- c. What are the minimum and maximum times during which abnormal current is permitted?
- d. What voltage is applied to the fuse?
- e. What is the normal ambient temperature at the fuse locations?
- f. Are there pulse characteristics involved in the circuit?
- g. Are there other requirements special to this application (mechanical or electrical characteristics) beyond the normal requirements of a fuse?
- h. What is the physical size which can be tolerated?

15.3 PROTECTIVE DEVICES, FUSES

The proper size fuse is selected after considering the type of load current it will pass. Where equipment is being protected, the fuse should be selected so that the load current meets the MIL-STD-975 derating. Where transients of short duration and relatively high amplitude are encountered as a normal current, the fuse rating may have to be two, three, or more times the value of the equivalent rms current, particularly if the transient reoccurs at a regular interval.

Some transient spike currents exist for just a few microseconds, others are measured in milliseconds. There might be a dwell in between these spikes when the current subsides to zero or to a value of only a small fraction of the transient peak value. The fuse selection is then based on two factors; (1) the fuse link must not melt while the transient current is building up to its peak; and (2) the equivalent rms value of the current over a long period of time must be below the rating of the fuse. The ampere rating of a fuse is always an rms value that is a measure of the heating effect of the current. This rating must be considered particularly in rectifier circuits in which half-cycle currents flow. The direct current values of half-cycle duration are average currents and are of a magnitude less than the rms value.

The fuse link must not melt while transient current is building up to its peak. This is a particular problem for the application engineer using sub-miniature fuses because of the relatively low ampere ratings available in these fuses. The sub-miniature fuse is available in ampere ratings from 1/100 ampere to 5 amperes. The fuse link in this ampere range is always a wire of very small diameter. Because of its small size, the wire has very little mass and therefore will reach its melting temperature quickly under transient conditions. For example, a one ampere sub-miniature fuse is current-limiting when a 5 ampere load is impressed upon it. This means that if the circuit is set to deliver five amperes, and is closed with a one ampere fuse installed, the current will never reach five amperes because the fuse link will melt while the current is still building up.

This is not a disadvantage. The thermal capacity of such a fuse is low, but so is the thermal capacity of the equipment it is protecting, and this equipment cannot afford to be heated up by such transients. A good example is a milliammeter or millivoltmeter having a full scale deflection of 5 or 10 milliamperes. A 10 or 20 mA fuse becomes current limiting around 200 percent of rated value. This characteristic allows the fuse to clear quickly before either thermal or mechanical forces can injure the meter movement.

15.3.3 Physical construction. Fuses are designed to carry 100 percent of current rating and blow rapidly at very slight percentages of overload. For example, they will open the circuit at a 200 percent overload within a maximum of 5 seconds. The greater the overload, the more rapidly the circuit opens. There is very little mass in the filament used, therefore, the reaction can take place very quickly under shortcircuit conditions. The filament is generally made of silver, platinum, or other precious metal alloys.

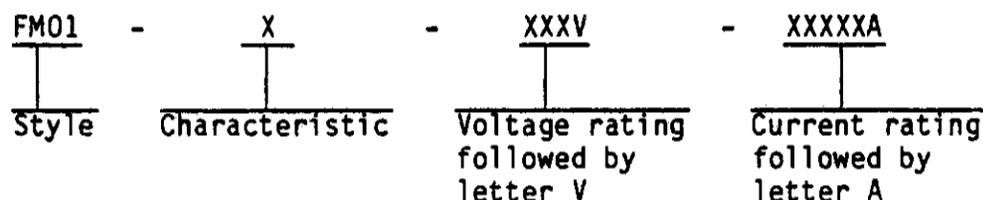
15.3 PROTECTIVE DEVICES, FUSES

These fuses are manufactured with wire diameters as low as 0.000020". Obviously this filament will open the circuit under adverse conditions before any damage can be done in other parts of the circuit.

There are three basic constructions for fast-acting fuses. The first, a bead-type construction, uses a small onyx bead holding two heavy wires, across which is placed a fine filament. The second is a filament-type construction employing a diagonal lineup to insure the constant blowing characteristics of the fuse; and the third, an element construction for heavy amperage fuses in this design.

By observing the characteristic curves found in MIL-F-23419, it will be noted that as the amperage rating increases there is an inherent lag, automatically built-in, due to the increase in mass of the fusible link. In the design of fast-acting fuses, a minimum amount of mass is desired in order to cause the fuse to open the circuit as quickly as possible.

15.3.4 Military designation. The military designation for fuses is:



15.3.5 Electrical characteristics.

15.3.5.1 Current rating. A fuse operated at its rated current consumes some electrical power which must dissipate in the form of heat. When operated above its rated current, a fuse must either operate or blow, which means that the fuse element has melted because of the additional heat.

Generally fuses are rated so that at 110 percent of rating, the temperature rise (from room temperature) at the hottest point on the fuse will not exceed 70 °C.

Under other mounting conditions or ambient temperatures the rating of a fuse must be adjusted up (uprated) or down (derated) for the increased or decreased subtracted heat provided by the mounting or environment.

15.3.5.2 Voltage rating. A fuse can be operated at any circuit voltage as long as the fuse is able to blow without suffering arc damage, and as long as it is sufficiently insulated.

When a fuse blows there is always a sharp break in the circuit that causes full circuit voltage to appear across the blown fuse; and in circuits where inductance is present, the voltage across the fuse may be substantially increased by inductive "kick." Under these conditions, a destructive electric arc may be formed within the fuse that continues to grow in size until the intense heat and pressure within the fuse literally causes it to explode.

15.3 PROTECTIVE DEVICES, FUSES

15.3.6 Environmental considerations. There are no unusual environmental instructions for fuses.

15.3.7 Reliability considerations. Consult paragraph 15.1.6 for reliability considerations associated with fuses. These considerations apply to most fuses used in space applications.

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16.1 SWITCHES, GENERAL

16. SWITCHES

16.1 General.

16.1.1 Introduction. This section contains information on the various types of switches used in electronic equipment. Switches are not included in MIL-STD-975 NASA Standard Electrical, Electronic, and Electromechanical (EEE) Parts List. The term "switch" applies to a wide spectrum of electromechanical devices used to make or break an electrical circuit. Relays, circuit breakers, and choppers are sometimes thought of as switches. However, those devices are dealt with in other sections of this manual.

Because switches are electromechanical, many considerations must be made prior to inclusion in equipment. These considerations are discussed in this section.

16.1.1.1 Applicable military specifications.

MIL-S-8805	Switches and Switch Assemblies, Sensitive and Push (Snap Action), General Specification for
MIL-S-22885	Switch, Push Button, Illuminated, General Specification for
MIL-S-24317	Switches, Multistation, Pushbutton (Illuminated and Non-Illuminated), General Specification for
MIL-S-3950	Switch, Toggle, General Specification for
MIL-S-8834	Switches, Toggle, Positive Break, Aircraft, General Specification for
MIL-S-3786	Switches, Rotary (Circuit Selector, Low-Current Capacity), General Specification for
MIL-S-6807	Switch, Rotary, Selector, General Specification for
MIL-S-15291	Switches, Rotary, Snap Action
MIL-S-24236	Switches, Thermostatic, (Metallic and Bimetallic), General Specification for
MIL-S-9395	Switches, Pressure, (Absolute, Gauge and Differential), General Specification for

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16.1.1.2 Switch types. The most widely used switches in military equipment can be grouped into five basic types.

- a. Push and sensitive
- b. Toggle
- c. Rotary
- d. Thermostatic
- e. Pressure.

16.1.2 General definitions. The following is a list of terms which are commonly used.

Contact resistance. The resistance of a pair of closed contacts as measured from terminal to terminal. This includes the circuit resistance of the individual contact members.

Contact voltage drop. The voltage drop across a pair of closed contacts as measured from terminal to terminal.

Pretravel. The distance or angle through which the actuator moves from free position to operating position.

Releasing force or torque. The releasing force or torque is the value to which the force or torque on the actuator must be reduced to permit the contacts to return to the unoperated position.

Sensitive switch. A switch having a snap action such that the speed of the moving contacts is independent of the speed of the actuator.

Switch life. The number of cycles of operation during which the electrical and mechanical performance of the switch will meet predetermined and stated life-limiting criteria.

Switch rating. The load-carrying and breaking ability of a switch.

16.1.3 General device characteristics. This section discusses the general characteristics of each type of switch. All types are available for ac or dc applications.

16.1.3.1 Push and sensitive switches. These switches are actuated by a reciprocating plunger and are available as very sensitive devices, or as devices carrying large current loads.

16.1 SWITCHES, GENERAL

16.1.3.2 Toggle switches. These switches are actuated by a bat handle and are available as very sensitive devices, or as switches carrying large current loads. Many types of toggle switches are available:

- a. Single-, double-, triple-, and four-pole
- b. Single or double throw
- c. Snap-action or momentary contact
- d. Locking or non-locking.

16.1.3.3 Rotary switches. These switches are actuated by the rotary motion of a shaft for the selection of any one or more of a number of circuits. Many types of switching arrangements are available for use in varying one or more functions such as voltage, frequency and/or resistance.

16.1.3.4 Thermostatic switches.

These switches are actuated by temperature change. They are available in two types of construction: Bimetallic element and nonbimetallic element actuated. Thermostatic switches are used for temperature protection, accurate temperature control, and as detection devices.

16.1.3.5 Pressure switches. These switches are actuated by pressure changes in liquid or gas applications. The switch consists of an electrical snap switch actuated through the displacement of a pressure-sensing device having an inherent spring rate where its displacement is proportional to the applied pressure. These pressure-sensing devices are of three general types:

- a. Capsule sensor
- b. Bourdon tube
- c. Bellows elements.

16.1.4 General parameter information. Both physical and performance factors must be considered when selecting manual switches. Human factors are equally important for efficient and accurate system performance.

Design considerations applicable to switch selection include the following:

- a. Type of action
- b. Contact rating
- c. Switching speed
- d. Environmental considerations

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- e. Capacitive effect on associated circuitry
- f. Electrical considerations
- g. Life requirements (in number of cycles).

16.1.4.1 Type of action. The type of action required is determined by the switch application. Obviously toggle switches cannot provide the multiswitching capability of rotary switches.

16.1.4.2 Contact rating. Contacts are usually given multiple ratings dependent on the type of load being acted upon. These ratings are resistive, lamp, motor, and inductive loads. Most switches are rated with the resistive load capability and, in most instances, at least one additional rating of the four listed herein. Table I is an example of a typical switch rating.

Current ratings are established at 25 °C. The values shown for multiple switches are amperes per pole, except for motor load.

For some loads, the inrush current at the instant that the switch makes contact is considerably higher than the current that flows during normal operation. Lamp, motor, and capacitive loads are examples of this. Table I shows the lamp load rating as about one-fourth the rating for a normal resistive load. Inrush currents for motor loads may be as much as 12 times the normal running load because of the lack of back emf. Inductive load ratings for both ac and dc are lower than the resistive load rating because of the longer duration of the arc on current break. Inrush current in a capacitive load circuit is high because the capacitor acts as a virtual short circuit until it has acquired some charge.

Table I gives ratings for not only maximum inrush current but also emergency current-breaking capacity. In many instances, the maximum current-making capacity may be the limiting factor rather than the running current capacity of the switch. The current, voltage and the characteristics of the current during make, break, and continuous duty must be carefully considered.

Ratings of contacts are usually given for room ambient temperature and include some safety factor to take care of the temperature rise of the switch. Temperature has a marked effect on switch current ratings, as is shown in Figure 1.

16.1.4.3 Switching speed. Switching speed may be an important parameter to consider when choosing a switch. The term "switching speed" means the duration of contact travel during a make or break function. This parameter is important from the standpoint of reducing any interruptive arc which may be formed, or decreasing the flashover time during the making of a switch. During the actual making of contact, a spring action is sometimes used to increase the speed of closing. This decreases the length of time that an arc, caused by voltage breakdown between the contacts, can cause pitting or burning. If the arcing during the make function is very severe, the contacts may weld together.

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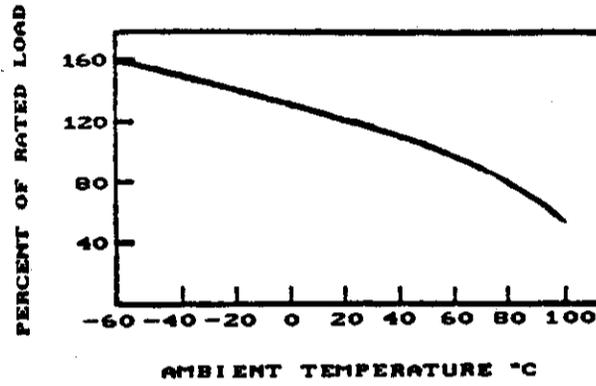


FIGURE 1. Switch current rating vs temperature for typical switch.

TABLE I. Typical switch ratings

Rating <u>1/</u>	Voltage (volts)	Current (amperes)
Lamp load	15 dc	10
	30 dc	7
	125 ac	4
Resistance load	15 dc	50
	30 dc	25
	125 ac	15
Inductive load	15 dc	25
	30 dc	15
	125 ac	11
Motor load	15 dc	40
	30 dc	20
	125 ac	6
Continuous current-carrying capacity (any voltage):		
	15 min of each hour	60
	5 min of each 1/2 hour	90
	1 min of each 1/4 hour	110
	5 sec of each 1/2 hour	250

16.1 SWITCHES, GENERAL

TABLE I. Typical switch ratings (Continued)

Rating <u>1/</u>	Voltage (volts)	Current (amperes)
Current-making capacity (Maximum in-rush on any type of load):	15 dc	100
	30 dc	70
	125 ac	40
Emergency current-breaking capacity (Opening circuit under emergency conditions for 50 operations only):	15 dc	225
	30 dc	100
	125 ac	20

1/ These figures are maximum current ratings for 10,000 operations. Longer life (more operations) can be expected when operated at less than maximum rating of switch.

During the break function, an attempt is made to decrease the speed to give the stored energy time to dissipate slowly, because an instantaneous opening will produce heavy transient currents across the contacts. This is especially true of dc circuits and inductive ac circuits. Pitting of contacts is usually more severe during the opening of the contacts. With switches used to interrupt heavy currents, it is sometimes necessary to employ arc suppressors or arc extinguishers. These may take the form of either a capacitor across the contacts to act as an energy sink, or a permanent magnet near the contacts to deflect the arc.

Contact Chatter. Whenever two objects collide, a force develops which causes them to rebound. The extent of rebound depends on the forces tending to restore them to contact, the relative masses, and the natural frequency of the supporting means.

With lamp loads, where the initial current inrush might be 10 or 15 times normal current, a switch exhibiting contact bounce might actually be making the circuit at 15 times the normal current for five or six bounces. This means that a switch being tested for 5,000 cycles might actually be closing this high inrush current at six times 5,000 or 30,000 cycles.

16.1.4.4 Environment. There are four environmental conditions that affect switch performance: temperature, altitude, mechanical vibration and shock.

- a. Ambient temperature. High ambient temperature may affect the lubricants used in some switches, reducing the viscosity and allowing the lubricants to flow out of the bearing areas and, in some cases, onto the contacts or insulating surfaces. If this occurs, improper lubrication of the shaft and/or plunger may hasten mechanical wear of

16.1 SWITCHES, GENERAL

these parts, and cause early mechanical failure. A film of lubricant on insulating surfaces has a tendency to trap dust and wear products which may reduce dielectric strength and insulation resistance. In switches with low contact pressure, lubricants present on the contact surface may increase contact resistance and, if dust particles are trapped, may even cause intermittent open circuits. While most switch manufacturers, through careful design and selection of lubricants, attempt to minimize these effects, it is still generally true that

continued operation in high ambient temperatures will shorten the life of a switch.

Extremely low ambient temperatures may also create problems. In switches that use lubrication on the contact areas, low temperatures may cause an increase in the viscosity of the lubricant to such an extent that it delays or prevents the closing of contacts, thus creating a high resistance contact.

- b. Altitude. The reduced barometric pressure encountered in high altitude operation reduces the dielectric strength of the air. This permits the arc to be struck at a lower voltage and to maintain itself longer, thus causing increased contact erosion. Use of switches in high altitude applications will therefore require derating in terms of loads and/or life.

In manned space flight, applications altitudes are such that the effect of gravity is lost. This permits particulate contamination to become weightless and float around in the switch housing. This can cause shorts between normally open contacts if the contaminant is conductive and can cause opens on normally closed contacts if the contaminant is nonconductive. This emphasizes the importance of hermetic sealing, clean room assembly, visual inspection and screening in these applications. Use of cadmium- or zinc-plated parts should be prohibited and nonmetallic parts used to a minimum because of outgassing and resulting contact contamination.

- c. Vibration. In any snap action switch, the contact pressure depends on the position of the actuating button. As the button is depressed, the operating point is approached, and the contact pressure decreases until the overcentering action takes place.

Most switches have good vibration resistance in either the free or the full overtravel position. Some switches do not withstand vibration if the operating plunger has been depressed almost to the operating point. Contact forces here have been reduced to a low value that depends on the remaining distance to be traveled until snap action occurs.

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If the switch is subjected to mechanical vibration, it is possible that the contact spring will reach a frequency which nearly corresponds to its fundamental frequency, or a harmonic. The vibration that results will cause the moving contact to chatter on the stationary contact.

Chatter caused by vibration can be of particular importance in digital circuits where making and breaking contacts can result in transmittal of erroneous information. The effect of vibration chatter can be minimized by using two sets of contacts in parallel. Each set should be selected to take the full current rating, since they will not make and break at the exact same time.

- d. Shock. Mechanical shock applied to switches may cause damage such as cracking of the switch body, insulating stack, or wafer; loosening of contacts from the wafers; or breaking of welds.

An electrical effect which is directly attributable to mechanical shock is contact bounce, which is a separation of contacts of the closed circuit. This is similar to contact chatter, but is usually of greater magnitude. Contact bounce is dependent on the contact mass and the spring constant of the contact arm, and may be severe enough to open a closed circuit or to close an open circuit.

Even if circuit malfunction does not result from contact bounce, the arcing it causes will materially shorten contact life and may generate electrical noise. Therefore, the susceptibility of switches to contact bounce must be studied with instrumentation of rapid response. Pulses produced by contact bounce must be considered in light of the circuit application. Voltage or current intermittencies which in one circuit would be completely inconsequential might badly disturb another, more sensitive circuit.

16.1.4.5 Electrical considerations. These are six basic factors that are important in the selection of a switch.

- a. Current Rating. This is based on the temperature developed within the switch under service conditions. Because of arcing and welding at the contacts, most heating (and consequent wear) occurs on making and breaking the circuit. Hence, the rate of operation also affects switch life. For ac loads, 60 operations per minute is generally considered the maximum rate at which full current capacity of the switch is available. The switch can, however, be operated at higher rates if the current is reduced, or if a decrease in switch life is acceptable. Ratings are normally based on continuous, steady-state current.
- b. Voltage. Maximum voltage rating depends on the air gap, or contact separation. A gap of 0.005 to 0.008 in. will permit a 250 Vac rating. A gap of 0.010 to 0.015 in. permits a 480 Vac rating, and a gap of 0.020 to 0.070 in. permits a 600 Vac rating.

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- c. Insulation resistance. This is the resistance between two normally insulated metal parts, such as a pair of terminals, measured at a specific high dc potential (usually 100 or 500 Vdc). Typical values for new switches are in the range of thousands of megohms. These values usually decrease during life as a result of surface contaminant build-up.
- d. Dielectric strength. This is a measure of the ability of the insulation to withstand high voltage without breaking down. During life, the deposition of contaminants and wear products on the surface of the insulation tends to reduce the dielectric withstanding voltage. In testing for this condition, a voltage considerably above rated voltage is applied, and the leakage current is measured. Test voltages are typically 1000 Vac plus twice the rated voltage.
- e. Effect of loads. On any switch, electrical erosion of the contacts occurs when an arc is drawn while breaking a circuit. This erosion normally tends to increase contact resistance, generate wear products by contamination of insulating surfaces, and reduce dielectric strength and insulation resistance. The amount of this erosion is a function of current, voltage, power, frequency, and speed of operation. The higher the current, the hotter the arc and the greater the erosion. The higher the voltage, the longer the arc will be maintained, resulting in greater erosion. In an inductive circuit the inductance acts as an energy storage device, which returns its energy to the circuit when the circuit is broken. The amount of erosion on an inductive circuit is in proportion to the amount of inductance.
- f. Contact resistance. This is the resistance of a pair of closed contacts which effectively appears in series with the load. Typical end-of-life criteria for this parameter is 20 m Ω .

16.1.4.6 Life requirements. In attempting to forecast life expectancy for a switch, both mechanical and electrical factors must be considered. In applications that do not require the switch to make or break large electrical loads, mechanical life is generally limited only by the fatigue characteristics of the spring. These characteristics, in turn, are influenced by the total travel required of the switch and the method of applying the actuating force. When overtravel is held within the prescribed normal limits, mechanical life can be expected to reach several million operations, regardless of the cycling rate. In most applications, however, electrical considerations are of major importance in determining switch life. Life is an inverse function of current made or broken. When determining life requirements, care should be taken to include the operations that take place during testing or screening of both the switch and the equipment that the part is used in. See Table II and Figure 2.

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TABLE II. Typical electrical ratings comparing various manual switches

Switch type	Rated current (amperes)		Rated voltage (volts)
	Resistive	Inductive	
Pushbutton	5	3	30 dc
	5	3	125/250 ac
	15	15	125/250 ac
	1.5 1.5		110 dc 250 ac
Toggle	20	12	30 dc
	1.5		110 dc
	15	15	230 ac
Rotary	15	15	125/250 ac
	0.5		125 dc
	0.25		250 dc

16.1.4.7 General load and life discussion. The problem of switch rating arises from the wide variety of requirements placed on the switch in various applications, and the sensitivity of the switch to changes in requirements. If an attempt were made to establish life ratings for all possible applications, the result would be an almost infinite variety of ratings. In an effort to simplify the problem, switch manufacturers, in cooperation with switch users and the military, have established certain reference loads, life requirements, environments, duty cycles, and failure criteria. These are arbitrarily established, and give a relative basis for comparison between different switch designs. They do not, however, match the actual requirements for most applications.

16.1.5 Reliability considerations. Switches are electromechanical devices subject to both electrical and mechanical failure. Contact failure can result from high in-rush or sustained high currents, or from the inductive kick when an inductive circuit is opened. These currents may cause intense heat and the possible welding of contacts. Careful consideration to derating should be given in these cases.

In selecting a switch for high-reliability or space programs, hermetically welded sealed units should be used where available. Terminals should have a glass seal and be of a hook design to provide proper stress relief for the seal. Parts should be of corrosion-resistant material with no cadmium or zinc plating. Use of nonmetallic materials should be minimized.

16.1 SWITCHES, GENERAL

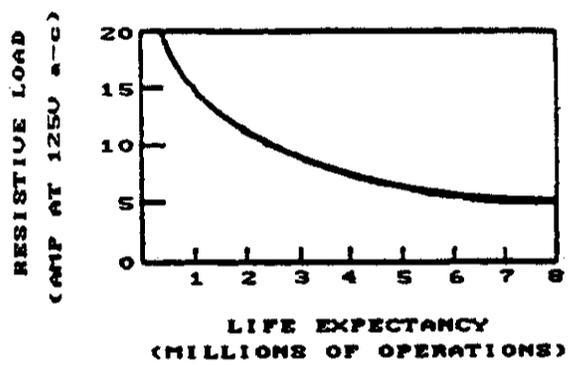


FIGURE 2. Life expectancy vs current for a typical switch.

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16.2 SWITCHES, PUSH AND SENSITIVE

16.2 Push and sensitive.

16.2.1 Introduction. Pushbutton and sensitive switches are actuated by a direct thrust in line with the button travel. They are available with numerous contact configurations and modes of operation. Common modes of operation are momentary contact, maintained contact, and sequential contact.

16.2.1.1 Applicable military specifications.

MIL-S-8805	Switch, Sensitive and Push
MIL-S-22885	Switch, Illuminated Pushbutton
MIL-S-24317	Switch, Multistation Pushbutton

16.2.2 Usual applications. Pushbutton and sensitive switches are a form of precision switch with integral pushbutton actuators. They are available with numerous contact configurations and modes of operation. Banks of pushbutton or sensitive switches can be individually operated or interlocked. The exact type or configuration is determined by the application.

16.2.3 Electrical ratings. Typical electrical ratings for push and sensitive switches are similar to electrical ratings for most other switches. Four types of loads are considered.

- a. Resistive
- b. Inductive
- c. Motor
- d. Lamp.

See Table I for typical electrical ratings.

16.2.4 Environmental considerations. Typical environmental requirements are found in MIL-S-8805, MIL-S-22885 and MIL-S-24317.

16.2.5 Reliability considerations. Refer to subsection 16.1 General, paragraph 16.1.5 Reliability considerations.

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16.3 SWITCHES, TOGGLE

16.3 Toggle.

16.3.1 Introduction. Toggle-action switches are available with two types of action, momentary contact and maintained contact. Additionally, they are available as two- or three-position switches with single, double, triple, or four poles.

A two-position toggle typically has these two positions at equal angles on each side of the vertical centerline of the mounting bushing. A three-position toggle has two extreme positions plus a center position. The center position is generally for the "OFF" condition with the two extreme positions representing "ON" conditions of the circuitry.

16.3.1.1 Applicable military specifications.

MIL-S-3950	Switch, Toggle
MIL-S-8834	Switch, Toggle
MIL-S-81551	Switch, Toggle, Hermetically Sealed

16.3.2 Usual applications. Toggle switches are widely used where simple make-and-break action is required, and are suitable for use on ac or dc circuits. Toggle switches are available with various actuating handles and subsequent switching actions in some 50 styles.

16.3.3 Electrical ratings. Typical electrical ratings for toggle switches are similar to electrical ratings for most other switches. Four types of loads are considered.

- a. Resistive
- b. Inductive
- c. Motor
- d. Lamp.

See Table I for typical electrical ratings.

16.3.4 Environmental considerations. Typical environmental requirements are found in MIL-S-3950, MIL-S-8834 and MIL-S-81551.

16.3.5 Reliability considerations. Refer to subsection 16.1 General, paragraph 16.1.5 Reliability considerations.

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16.4 SWITCHES, PRESSURE

16.4 Pressure.

16.4.1 Introduction. Pressure switches are switches whose response is a function of the gas or liquid pressure which they are designed to regulate and control.

The switching action of a pressure unit usually falls into two categories: the creep type and the snap-acting variety. The latter is preferable for applications where vibration capability and inductive load carrying capability are required. The creep type, however, can offer very close tolerances with regard to its pressure differential rating--as low as ± 1 percent.

16.4.1.1 Applicable military specification.

MIL-S-9395

Switch, Pressure

16.4.2 Usual applications. Applications include response to altitude, liquid pressure liquid level, and air flow. Switches may respond to absolute, gauge, or differential pressures. By means of adapting elements, these switches may be applied to a great variety of applications.

By using more than one switch, control of separate circuits at different pressure or temperature steps can be provided.

16.4.3 Electrical ratings. Typical electrical ratings for pressure switches are low, below 1 amp, and supply input to instruments. Usually a relay will be added to the circuit when the pressure switch must control a large load.

16.4.4 Environmental considerations. Typical environmental requirements are found in MIL-S-9395.

16.4.5 Reliability considerations. Refer to subsection 16.1 General, paragraph 16.1.5 Reliability considerations.

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16.5 SWITCHES, ROTARY

16.5 Rotary.

16.5.1 Introduction. Rotary switches are actuated with a twisting action and are generally available with either momentary contact or maintained contact. Rotation can be either unlimited (turned through more than one complete circle) or limited to 360 degrees or less, after which the direction of rotation must be reversed.

A rotary switch may have many points of actuation with several decks of contacts and combinations of actuating cans.

16.5.1.1 Applicable military specification.

MIL-S-3786	Switch, Rotary (Circuit Selector, Low-Current Capacity) General Specification
MIL-S-6807	Switch, Rotary, Selector, General Specification for
MIL-S-15291	Switch, Rotary, Snap Action
MIL-S-22710	Switch, Rotary (Printed Circuit)

16.5.2 Applications. Rotary switches are used for the selection of any one of a number of circuits or combinations of circuits with a rotary motion of the shaft. Rotary switches can handle a great many connections. The basic contact arrangements may be expressed by the number of poles and the switch positions or decks per pole.

16.5.3 Electrical ratings. Typical electrical ratings for rotary switches are low, below 2 amps. Usually a relay will be added to the circuit when the rotary switch must control a large load.

16.5.4 Environmental considerations. Typical environmental requirements are found in MIL-S-3786, MIL-S-6807, MIL-S-15291, and MIL-S-22710.

16.5.5 Reliability considerations. The contacts of a rotary switch are usually of the sliding type, providing the self-cleaning necessary for low contact resistance and long life. The rotary switch will usually exceed life and reliability referenced in subsection 16.1 General, paragraph 16.1.5 Reliability considerations.

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16.6 SWITCHES, THERMOSTATIC

16.6 Thermostatic.

16.6.1 Introduction. Thermal switches (thermostats) are used either for the indication or control of temperature, or in a protective function. The majority of thermal switches are simple thermostatic devices whose performance depends upon the action of a bimetallic element. The principal design factors relate to accuracy, repeatability, temperature range, and thermal lag.

16.6.1.1 Applicable military specification.

MIL-S-24236

Switches, Thermostatic, Bimetallic Actuated

16.6.2 Usual applications. Temperature-actuated switches provide switching action in response to temperature changes. Usually the objective is to maintain a specified temperature within the system. However, the devices are also used for over- or under-temperature protection.

16.6.3 Electrical ratings. Typical electrical ratings for thermal switches are low, below 1 amp, and supply input to instruments; usually, a relay will be added to the circuit when the thermal switch must control a large load.

16.6.4 Environmental considerations. Typical environmental requirements are found in MIL-S-24236.

16.6.5 Reliability considerations. Refer to subsection 16.1 General, paragraph 16.1.5 Reliability considerations.

17.1 RELAYS, GENERAL

17. RELAYS

17.1 General.

17.1.1 Introduction. The American Standards Association defines a relay as "an electrically controlled device that opens and closes electrical contacts to effect the operation of other devices in the same or another electrical circuit."

Although this definition states control in the "same" or "another" electrical circuit, an implicit characteristic of the electromechanical relay is the opening and closing of contacts to control a load, or loads, in circuits isolated from the controlling input and other contacts. Controlling an electromechanical relay is most commonly done with the application of a specified voltage or current to two input terminals. A coil within the relay translates control-signal electrical energy into mechanical energy, causing mechanical action to open or close the isolated contacts, controlling signals through the contacts.

This section contains information on the various types of relays used in electronic equipment. Many types of electrically controlled switching devices are described by the term "relay." However, the following discussion is confined to the selection and application of electromechanical, current-operated switching devices which find general usage in space applications. MIL-STD-975 NASA Standard Electrical, Electronic, and Electromechanical (EEE) Parts List includes only MIL-R-39016 relays. The other relays are included for general information.

17.1.1.1 Applicable military specifications.

MIL-R-5757	Relay, Electromagnetic, General Specification for
MIL-R-6106	Relay, Electromagnetic (Including Established Reliability (ER) Types), General Specification for
MIL-R-28776	Relays, Hybrid, Established Reliability, General Specification for
MIL-R-28894	Relay, Hybrid or Solid State, Sensor, Established, Reliability, General Specification for
MIL-R-39016	Relay, Electromagnetic, Established Reliability, General Specification for
MIL-R-83726	Relay, Hybrid and Solid State, Time Delay, General Specification for
MIL-R-83407	Relay, Reed, Mercury Wetting, General Specification for
MIL-R-83516	Relay, Reed, Dry, General Specification for

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17.1.1.2 Applicable federal standard.

FED-STD-209

Clean Room and Work Station Requirements,
Controlled Environment.

17.1.2 General definitions. A list of terms which are commonly used in relay engineering and generally accepted by the electrical and electronic industries are as follows:

Ambient temperature. Ambient temperature is the temperature of the surrounding medium.

Armature. The armature is the hinged or pivoted moving part of the magnetic circuit of an electromagnetic relay. It is sometimes used in a general sense to mean any moving part which actuates contacts in response to a change in coil current.

Bounce time. Bounce time is the interval from the initial closure of the contacts until the uncontrolled making and breaking of contact ceases.

Chatter. Chatter is sustained rapid opening and closing of contacts. It is caused by uncompensated ac operation, mechanical vibration, and shock or other causes.

Coil. A relay coil is a magnetic winding to which energy is supplied to activate the relay.

Coil resistance. Unless otherwise specified, coil resistance is the dc ohmic resistance of the coil, measured at the coil terminals at 25 °C.

Contact bounce. Contact bounce is the uncontrolled making and breaking of the contacts when the relay contacts are moved to the closed position.

Contact nomenclature. Each of the moving contacts of a relay constitutes a pole of the relay.

- a. A combination of a stationary contact and a movable contact which are closed when the relay coil is deenergized is referred to as form B or normally closed contacts and is abbreviated NC.
- b. A combination of a stationary contact and a movable contact which are closed when the relay coil is energized is referred to as form A or normally open contact and is abbreviated NO.
- c. A combination of two stationary contacts and a common or movable contact which engages one of them when the coil is energized and engages the other when the coil is deenergized is called transfer, form C or double-throw contacts and is abbreviated DT.

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Contact resistance. Contact resistance is defined as the total electrical resistance of the contact system as measured at the terminals.

Contactor. A term sometimes used for a relay with heavy-duty contacts.

Control voltage. The voltage applied to an input which results in a change of state in the output of a relay.

Dropout current or voltage. Dropout current or voltage is the current or voltage at which all contacts will revert to the de-energized position. The relay will be considered released when all contacts have returned to their normal or nonoperated position.

Dropout time. Dropout time is the time interval from the removal of power to the coil until the NC contacts close; some specifications include contact bounce time in dropout time.

Dry circuits. Dry circuits are those circuits in which the relay does not perform a switching function on an energized circuit path.

Header. A header is the part of a hermetically sealed relay through which the electrical terminals pass.

Hold voltage. Hold voltage is the voltage at or above which the armature is maintained in its operated position.

Low-level circuits. Low-level circuits are those circuits which function in the millivolt or microampere range.

Miss. A miss is a failure of the contact, for any reason whatsoever, to establish a circuit as required within the limits as specified.

Operate time. Operate time is the time interval from the application of nominal power to the coil until the NO contacts close; some specifications include contact bounce time in operate time.

Pickup current or voltage. Pickup current or voltage is the maximum current or voltage required to operate the relay. The relay will be considered to have operated when all contacts have functioned.

Rated (nominal) coil voltage. Rated coil voltage is the coil terminal voltage at which the relay is designed to meet all specified electrical, mechanical, and environmental requirements.

17.1.3 General device characteristics. The following classifications define the general characteristics for various types of relays.

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17.1 RELAYS, GENERAL

17.1.3.1 Classification by configuration.

- a. Armature. The armature relay operation depends upon energizing an electromagnet which attracts a hinged or pivoted lever of magnetic material to a fixed pole piece. The hinged or pivoted lever is called the armature. The actuating coils may be operated with ac or dc voltage. Relays operated on direct current have greater life expectancy than ac relays.
- b. Hybrid. A relay with an isolated input and output. The input is a solid state device which controls an electromechanical output. The switching characteristics are dictated by the electromechanical output.
- c. Reed. A reed relay is operated by an electromagnetic coil or solenoid which, when energized, causes two flat magnetic strips to move laterally to each other. The magnetic reeds serve both as magnetic circuit parts and as contacts. Because of the critical spacing and the frailty of the arrangement, the reeds are usually sealed in a glass tube.
- d. Sensor relay. A sensor relay detects specified functions (for example, frequency, phase sequence, voltage level) and changes the output when the functions are within specified limits. The relay may incorporate time delay with the switching operation.
- e. Solid State. These are relays incorporating only semiconductor or passive circuit devices. There are no moving parts, so therefore there is no bounce or chatter, and they have fast response and long life; however, the number of designs available is still quite limited and at present only single pole devices are available.
- f. Time-delay.
 1. A delay in the operate time or the dropout time, or both, of the armature type relay may be obtained by placing a conducting slug or sleeve on the core in the proper position. This produces a counter magnetomotive force which produces a desired time delay. When the slug is placed on the core nearest the armature gap, a delay in operate time is obtained. Placing the slug farthest from the armature gap results in a delay in dropout time.
 2. The most common method of producing a time delay is the use of a separate circuit, usually in the same package, to produce either a fixed time delay or in some cases an externally adjustable delay in the time before the relay coil itself is energized.

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17.1.3.2 Classification by application. Since classifications are of an arbitrary nature, any particular relay design may fall into one or more categories. For example, a low level relay may also be a latching relay or a sensitive relay.

- a. General purpose. Relays having an ac or dc voltage rated coil whose contacts are rated resistive up to and including 10 A. The term general purpose may be used when discussing nonlatching relays.
- b. Intermediate level. Relays used in a load application where there is insufficient contact arcing to effectively remove surface residue from the organic vapor deposits on the contact surface, although there is sufficient energy to cause melting of the contact material.
- c. Latching. A bistable polarized relay having contacts that latch in either position. A signal of the correct polarity and magnitude will reset or transfer the contacts from one given position to the other.
- d. Low-level. Relays intended specifically for the switching of low-level or dry circuits. In these circuits only the mechanical forces between the contacts affects the physical condition of the contact interface, that is, there are no thermal or electrical effects; e.g., arcing. The current and open circuit voltage are generally defined as being in the microampere, millivolt range.
- e. Power. Relays intended for switching loads in excess of 10 A.
- f. Sensitive. Relays which are defined in terms of coil resistance and maximum operate current. The reduced coil power required to operate the relay is characteristic of a sensitive relay. It is accomplished by increasing the ampere-turns, and thereby the resistance, of the coil.

17.1.4 General parameter information.

17.1.4.1 Design considerations. Physical and electrical characteristics of the relay can be varied almost infinitely to handle different requirements; however, there is a very strong interdependence among the relays' mechanical parts and electrical system. For these reasons, comparable performance curves for similar relays are almost meaningless.

Nevertheless, selecting the best relay in terms of required performance at minimum cost is relatively straightforward. It involves two primary steps:

- a. Determining all factors pertinent to the application.
- b. Translating the application requirements into a technically sound relay specification.

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Design considerations applicable to relay selection include the following:

- a. Coil
 1. Supply voltage, current, and type of power (dc or ac including frequency)
 2. Resistance and tolerance
 3. Duty cycle
 4. Operate pickup and drop-out values
- b. Contacts
 1. Load characteristics (dc or ac resistive, inductive, capacitive, motor, lamp. If ac, the frequency)
 2. Normal load current
 3. Worst case load level
 4. Normal watts load
 5. Open circuit voltage
 6. On-off cycle and frequency of operation
 7. Operate and release time
 8. Life
- c. Environmental considerations, including temperature effect on coil current.
- d. Physical considerations
 1. Size
 2. Mounting
 3. Terminations
- e. Definition of switching requirement (open, close, transfer, double contact arrangement, etc.)
- f. Assurance that circuit is designed to allow minimum stress on contacts.

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Table I lists relay requirements that may need consideration.

TABLE I. Relay requirement check list

Characteristic	Description
Control signal Type	ac, dc or combination
Sensitivity	Input power to control circuit at maximum rated input voltage
Maximum actuating signal	Level of input required to effect switching
Minimum release signal	Input level at which contacts return to normal condition
Maximum overdrive	Absolute maximum prolonged input voltage
Input transient protection	Maximum transient input signal expected
Thermal stability	Allowable variation in maximum actuating signal and minimum release signal over specified temperature range
Switching Arrangement	Number of switching circuits and configuration
Current rating	Magnitude resistive, inductive, lamp, or motor
Isolation	Required isolation from input circuit and between switching circuits
Leakage	Maximum permissible open-circuit leakage
Saturation	Maximum forward voltage drops at rated load
Response	Response time from application of input signal to completed switching
Transfer time	Transfer time of SPDT common lead, make-before-break or break-before-make and dwell-time snap action required
Load power	Frequency for ac and polarity for dc

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TABLE I. Relay requirement check list (Continued)

Characteristic	Description
Switching (Cont)	
Open-circuit with-standing	Maximum continuous load voltage a nonconducting contact must withstand
Transient protection	Maximum transient voltage anticipated in load circuit
Step voltage	Maximum anticipated rate of change of load voltage rise
Cross talk	Signal interference level acceptable in "multicontact" relays
Overload	Maximum nonrepetitive overload expected
Radio noise	Acceptability level of internally generated radio noise
Auxiliary power	
Voltage available	Type of auxiliary voltage available
Isolation	Normally common with load supply
Power level	Maximum power required from auxiliary supply
Voltage range	Maximum voltage variation of auxiliary power from nominal
Transient level	Maximum voltage transients anticipated on auxiliary voltage
Environment	
Temperature	Operating and nonoperating temperature extremes
Shock-vibration	Maximum levels anticipated in use
Package requirements	
Dielectric	Insulation properties between isolated terminals
Size	Maximum envelope dimensions
Termination	Required terminal wiring
Mounting	Mounting methods and dimensions

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17.1.4.2 Coil requirements. The coil characteristics determine the pull on the armature. They may be expressed as ampere turns, amperes, watts, volts or resistance. Any one of these factors may dictate the use of a particular coil. The current available for the relay coil may be only a few milliamperes, in which case a large number of turns will be required to supply the required ampere-turns to make the relay operate properly. To assure positive operation under severe conditions, more than normal power input to the relay coil may be necessary.

- a. Coil resistance. Because of variations in wire, spool body dimensions, winding techniques, etc., it is impractical to attempt to wind a coil to a precise resistance. Generally, the coil resistance will vary from the nominal by ± 10 percent. For high resistance coils such as those used in sensitive relays the size of wire requires that this tolerance be increased to ± 15 percent or ± 20 percent. For low resistance coils a lower tolerance can be held although it is seldom required.
- b. Coil suppression. When a relay coil is turned off, the inductive energy stored in the coils magnetic field can create surge voltages of up to 1500 V on a dc power line. With the wide use of solid state circuitry, relay coils must be suppressed to limit the surge voltages. The suppression device absorbs and dissipates the energy in the coil. Suppression methods should be selected to minimize the affect on dropout characteristics which directly affect contact life. There are several different methods of suppression and each method has disadvantages.

The bifilar coil relay has two windings; a power winding and a shorting winding which absorbs the inductive energy from the power winding. The use of bifilar windings increases the dropout time and can increase bounce and arcing of the contacts. It is not polarity sensitive.

The use of a resistor in parallel with the coil is the simplest and oldest suppression technique. The resistor increases the power requirement for operation and like the bifilar coil, increases dropout time, bounce, and arcing.

The use of a diode is an effective method for suppression and is widely used. It is polarity sensitive and affects dropout, bounce, and arcing.

The use of back-to-back zener and diode or a zener-zener combination is the most effective method of suppression. These combinations have the least effect on dropout time, bounce, and arcing. The zener diode is polarity sensitive.

- c. Operate (pickup) and dropout voltage and current. Disregarding the increase in temperature resulting from the heating effect of the current flowing through the coil, coil resistance will be approximately

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140 percent higher at 125 °C than it is at the 25 °C ambient temperature. Under the same conditions when the voltage across the coil is held constant, the corresponding coil current and hence operating ampere-turns at 125 °C will be approximately 72 percent of the operating current at 25 °C ambient temperature. The increase in coil resistance and resulting decrease in power may cause marginal relay operation.

Coil resistances are normally specified at 25 °C. For the temperature of interest, the actual resistance can be approximated from the following formula:

$$R = R_{25} [1 + 0.0038 (T - 25)]$$

Where:

R = Actual coil resistance

R₂₅ = Coil resistance at 25 °C

T = Ambient temperature in °C

For example, at an ambient temperature of 125 °C, a 600-Ω coil will have a resistance of:

$$\begin{aligned} R &= 600 [1 + 0.0038(125 - 25)] \\ &= 600 (1 + 0.38) = 828 \Omega \end{aligned}$$

at -65 °C

$$\begin{aligned} R &= 600 [1 + 0.0038 (-65 - 25)] \\ &= 600 (1 - 0.342) = 394 \Omega \end{aligned}$$

The above examples considered only coil resistance change due to ambient temperature changes. Application of power to the coil causes heating and hence changes the coil resistance. To obtain the worst condition for high temperatures, this change must be added to the ambient temperature. Figure 1 shows the comparative values of coil resistance versus ambient temperature with and without coil voltage applied.

Care must be taken to insure that the relay will operate correctly at the maximum temperature. For example, a relay with a 600-Ω coil has a specified maximum pickup voltage of 13.5 V at 25 °C. The pickup voltage at any temperature can be calculated from the following formula:

$$E_{25} [1 + 0.0038 (T - 25)]$$

The formula is based upon a voltage shift of 0.38 percent per degree Celsius.

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From the above example, the maximum pickup voltage at 125 °C would be:

$$E_{125} = E_{25} [1 + 0.0038 (125 - 25)]$$

$$E_{125} = 13.5 (1 + 0.38)$$

$$E_{125} = 18.6 \text{ V}$$

Note that the pickup voltages listed in the various specifications are for relays where the case temperature is equal to ambient temperature. The designer cannot disregard the effects of temperature increase due to coil heating.

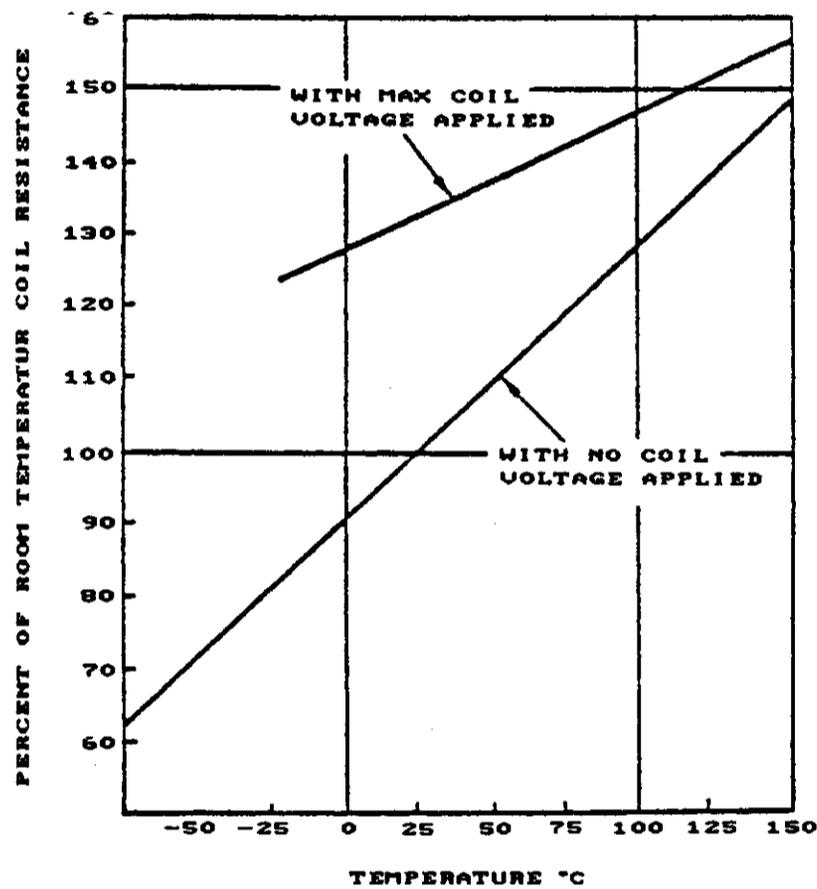


FIGURE 1. Coil resistance variation with temperature.

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The 18-V pickup at 125 °C is important since some military specifications require this for relays designed to operate on 26.5 V systems.

At low temperatures the operate voltage will decrease at a rate proportional to the decrease in coil resistance. Thus a relay which operates at 13.5 V at room temperature will operate at $13.5 (1 - 0.342) = 8.9$ V at -65 °C.

Maximum and minimum release voltages are also affected by ambient temperature in the same manner as the pickup voltage.

$$E \text{ (at } +125 \text{ °C)} = 1.38 \times \text{maximum release voltage at } 25 \text{ °C}$$

$$E \text{ (at } -65 \text{ °C)} = 0.658 \times \text{minimum release voltage at } 25 \text{ °C}$$

Ideally, operate and release currents should not be affected by changes in ambient temperature. Because of the changes in the spring modulus of the movable contacts, and because of changes in fits and clearances due to expansion or contraction of parts, considerable variation does occur. Over the range from -65 to +125 °C, operate and release currents may increase by as much as 10 percent over the 25 °C value and decrease by as much as 20 percent. Normally the value will increase at low temperature and decrease at high temperature, but this is not an infallible rule.

The relay will not operate below the rated coil voltage.

- d. Response speed. Mass and inertia of the armature and movable contact element, and electrical losses of the circuit, affect the operating speed. Some small relays operate in 2 to 3 ms, while larger units have pickup times in the 15 to 25 ms range. The greater the current or power over the minimum required to operate the relay, the faster the action.

Dropout time is usually faster than the operate time, and is almost entirely dependent upon parameters of the relay, such as spring rates and residual gaps.

17.1.4.3 Contact considerations.

17.1.4.3.1 Relay contact arrangements. An important consideration for relay applications is the contact arrangement. The contact arrangement is the various combinations of different basic contact forms that make up the entire relay switching structure. Relay contact notations are given in the following order.

- a. Poles. Each movable contact of a relay and its associated normally open and normally closed contacts constitutes a pole.

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- b. Throws. Double throw transfer contacts abbreviated DT, are a combination of two stationary contacts and a movable contact which engages one of the stationary contacts when the coil is energized and engages the other when the coil is unenergized. Contrasted with double-throw contacts, normally open or normally closed single contact are called single-throw contacts, abbreviated ST.
- c. Normal position. A combination of a stationary contact and a movable contact which are engaged when the coil is unenergized, is referred to as back, break, form B or normally closed contacts and is abbreviated NC. A combination of stationary contact and a movable contact, which is engaged when the coil is energized, is referred to as front make, form A or normally open contacts, and is abbreviated NO.
- d. Double break. A combination, abbreviated DB, in which a movable contact simultaneously makes and simultaneously breaks connection between two stationary contacts. For normally open contacts, this combination may be called doublemake contacts. All contacts are single break except when noted as double break; example: DPST NCDB designates double pole, single throw, normally closed, double-break contacts.

The common contact configurations are shown in Table II. Other configurations are available and are shown in the referenced relay specifications.

17.1.4.3.2 Contact configurations.

- a. Number of circuits. Basic to the operation are the number of circuits to be controlled and the type of switching required for each. Many possible combinations of contact arrangements can be used. Multiple contact sets can be combined within one relay package.
- b. Contact loads. After the number of contacts has been determined, the electrical load on each set of contacts must be analyzed. Open-circuit voltage and whether it is ac or dc must be specified. The ac frequency should be noted.

If the load is inductive, an effort should be made to determine the power factor and the amount of inductive reactance, or at least to describe the load, such as solenoid or contractor. If the load is a motor, complete information should be given about size, horsepower rating, and starting current.

A tungsten filament lamp load can be very difficult to switch. Contacts used to close the circuit to a cold filament must handle a current of ten times the steady state current. A 5-A contact, which might generally be considered adequate to operate 500 W from a 115 Vac source, is completely inadequate for a 500 W lamp, since the initial starting current would be on the order of 50 A. Such high surge-currents may result in sticking or welding of the contacts.

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TABLE II. Contact configurations

Form	Description	USASI symbol
A	Make or SPSTNO	
B	Break or SPSTNC	
C	Break, make, or SPDT (B-M),	
X	Double make or SP ST NO DM	
Y	Double break or SP ST NC DB	
Z	Double break, Double make SP DT NC-NO (DB-DM)	

Duty cycle and frequency of operation should also be specified in connection with contact performance. Some contact systems fail after relatively few operations when operated at a high rate of frequency, whereas the same contacts could handle the same loads many times when switched less frequently. Shortened life at high operational frequency is caused by heat developed at the contacts.

Refer to paragraph 17.1.4.6 Electrical considerations for an indepth discussion of contact ratings.

- c. Contact life. In many applications, relays may be required to operate many thousands or perhaps millions of times in order to provide an acceptable minimum life. A realistic appraisal must be made of each situation.

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As the contacts start to close, the material at the point of initial interface deforms until the contacting area supports the contact force. On a microscopic level, many point-contacts take place to form the electrical connection and carry the load current. If the current density is too high, localized melting takes place, and additional point contacts are engaged until there is sufficient surface area to carry the load.

The selection of contact material is based on the intended applications. Silver and silver alloys are normally used for power loads. Silver has excellent electrical and thermal characteristics. Arcing can precipitate carbonaceous products on the surface, normally in a ring around the primary contact points. The deposits can contribute to higher contact resistance, although the carbon is desirable to the extent that it minimizes sticking or welding in high current applications.

Gold plated silver contacts are commonly used in dry circuit or low level applications where stable contact resistance is essential. Gold has a very high resistance to surface film formation. It does exhibit poor resistance to sticking or welding, and it has poor mechanical deformation and wear characteristics.

High-current density at the point contact locations, during the first instant of contact closure, can cause contact surface melting, even at fractional ampere loads. This phenomenon is of practical concern in that it can result in contact sticking and metal transfer which potentially reduces long contact life. The effect is amplified by slow contact operation due to reduced coil voltage, slow rise time of the power supply, and circuit or line capacitance. Other factors that affect current density are high inrush current for lamp loads, switched motor loads, capacitive loads without current limiting resistors, and transformers. Figure 2 details the effect on contact life and thereby reliability by derating of the contact load.

With adequate arc suppression, contact load life can be extended to nearly the mechanical life expectancy. Initial values of resistance and capacitance for an RC arc suppression network may be calculated from:

$$R = (E/10) I(1+50/E), \text{ and } C = I^2/10,$$

Where:

R = resistance (ohms)

E = voltage before closing (volts)

I = current before opening (amperes)

C = capacitance before closing (microfarads)

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Peak rather than rms values of voltage and current must be used to calculate arc suppression of ac loads.

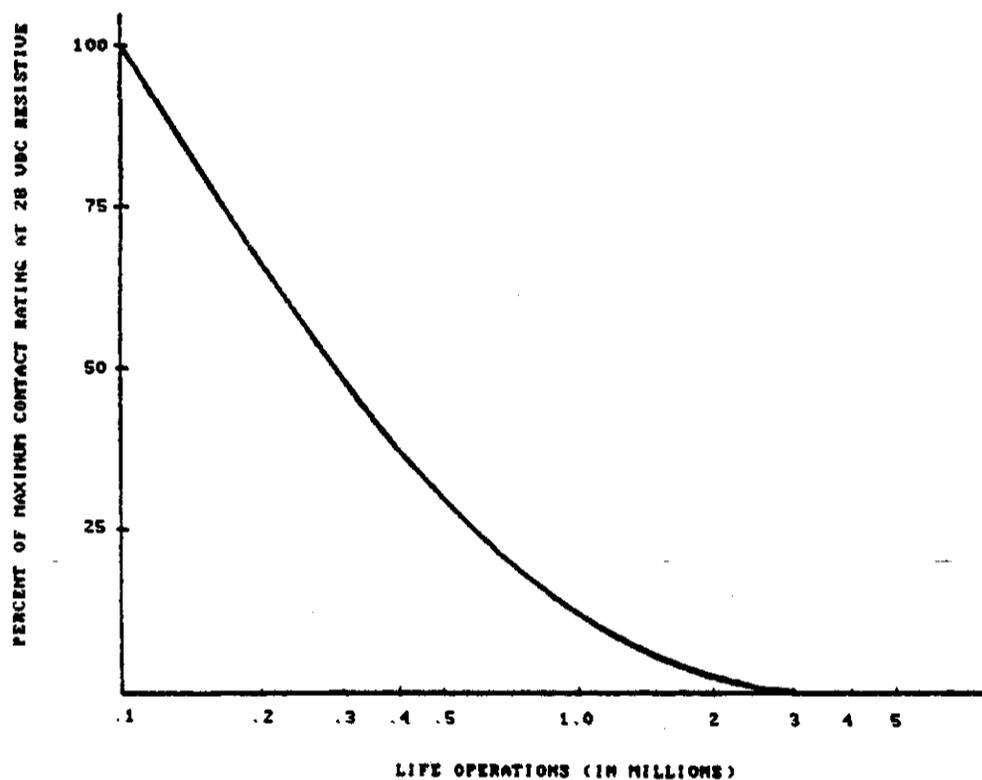


FIGURE 2. Effects of derating on contact life.

To ensure adequate suppression the RC network should be tested. If necessary, resistance and capacitance values can be adjusted to eliminate arcing at the contacts.

Several other systems are commonly used for arc suppression, such as resistors alone, capacitors alone, diodes, diodes and resistors, back-to-back diodes, neon glow lamps, magnetic blowouts, noninductive windings, and varistors.

For further details, consult paragraph 17.1.4.6 of this section.

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17.1.4.4 Environmental considerations. Ambient temperature affects operation of the relay and the ability of the contacts to switch and carry the circuit load. Because the coil of an electromagnetic relay is usually wound with copper magnet wire, compensations for the change in resistance due to change in temperature must be made. A MIL-R-5757, MIL-R-6106 or MIL-R-39016 relay requires operation at a maximum ambient temperature of 125 °C. If a 24 Vdc relay is considered for such an application, it must be capable of picking up at 18 V or less at the maximum ambient temperature. The relay must pull in at approximately 15 V at room temperature in order to pickup at 18 V at 125 °C. If this relay is required to dropout at 5 V at a temperature of -65 °C, it may be necessary to establish the dropout point when measured at room temperature as high as 10 or 11 V. Thus a close-differential relay may be required, which is another reason for keeping the pickup and dropout points as far apart as possible.

Other factors which may be grouped under general environmental conditions are high humidity, corrosive or explosive atmosphere, and dusty or dirty conditions. Explosive atmospheres are especially critical because of possible arcing of the contacts. These factors affect the protection provided for the coil, the plating or other finish required on metal parts, the insulating materials, and finish or treatments required to ensure serviceability. Many military applications dictate that hermetically sealed relays be used.

In most military applications, effects of shock, vibration, and linear acceleration have to be considered. It is possible to make certain types of relays that will resist vibration effects up to 3000 Hz at a level of 30 G and shock at a level of 100 G.

Environmental considerations are discussed in greater detail in the sections devoted to specific relay types.

17.1.4.5 Physical considerations.

- a. Enclosures. Many types of enclosures are available to protect the relay from external conditions, particularly high humidity and dirt. Relays may be loosely classified according to the degree of protection offered by the enclosure. Such classifications include the following: unenclosed, partially enclosed, enclosed, sealed, gasket sealed and hermetically sealed. It can be seen that, in common with other relay features, the relatively simple matter of enclosures is subject to considerable variation.

With the unenclosed relay, no effort is made to protect the relay or its parts from atmospheric conditions. Between the totally unprotected relay and the hermetically sealed type come the several variations noted previously in which the contacts or coils (but not both) may be enclosed, or in which the entire relay is enclosed but is not airtight, or the partially sealed type in which the coil or contacts (but not both) may be enclosed and contacts in an airtight container. The sealed relay has both coil and contacts in an airtight container, the seal of which may be broken for adjustment.

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The hermetically sealed relay is made airtight by a sealing process which involves fusing, or welding, and it does not use a gasket. Usually the air is removed and replaced by an inert gas under pressure. It cannot be unsealed and resealed without special equipment. This is usually performed under clean room conditions. In high-reliability applications, it is mandatory that the relays be hermetically sealed and that they be given an internal atmosphere of dry nitrogen. This activity should all be accomplished in a room meeting Class 100 cleanroom conditions as specified in FED-STD-209. A design approach that is sometimes used to reduce the chance of contact contamination is to have the contacts and coil in two separate adjacent hermetically sealed chambers in the same housing. This design increases the size and cost of the unit.

The different types of enclosures mentioned above offer different degrees of protection. The hermetically sealed enclosure offers the greatest protection, because it insulates against such elements as moisture, harmful gases, and foreign particles, which are the most common causes of relay failure. It also eliminates the increased arcing induced by low atmospheric pressures at high altitudes.

- b. Terminals. Terminals are available in a considerable variety of styles. They generally are made of round wire with material and size dependent upon type of enclosure, header design, and current and voltage requirements.

The number of terminals in the header will be determined by the number of poles and throws, and the necessary connections for the coil. An individual terminal with a glass or ceramic insulating bead for each may be used. The other scheme is to have a glass insulator with multiple terminals. The distance between terminals will determine the allowable voltage.

The type of terminals to use on a sealed relay depends upon the relay application. If, for example, it is to be used in a computer where convenient replacement is desired, then the plug-in type would be best. Plug-in type relays in the referenced military specifications have gold plated terminals to minimize terminal to socket resistance for plug-in applications. If the relay is mounted inside a piece of equipment subject to shock and vibration, then the solder type terminal is preferred. These terminals should be of a solder hook variety to reduce the stress on the header.

- c. Miniaturization. Miniaturization of relays has been going on for some time. A relay that was considered miniature several years ago may be big and awkward compared to its counterpart today. Relay manufacturers are devoting a lot of time and effort to the problem of miniaturization. The problem is complicated by the fact that the conditions requiring miniaturization also require the relay to withstand higher temperatures

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and more shock and vibration. It is not only a matter of reducing all dimensions, but also of utilizing new materials in new designs to obtain longer operating life, greater environmental resistance, and greater reliability. Relays are available in several designs packed in TO-5 transistor style cases with pin terminals or wire leads. This relay includes electromechanical, hybrid, and solid state devices.

17.1.4.6 Electrical considerations. The prime electrical considerations in selecting a relay are contact rating and coil voltage. The contact ratings and coil voltage of the relays described in this section are based upon MIL-R-5757, MIL-R-6106, and MIL-R-39016, the most commonly used military specifications.

The resistive load rating is that load which the relay can be expected to switch for 100,000 operations minimum at the maximum ambient temperature, (usually 125 °C) and at a cycling rate of 20 cycles per minute with a 50 percent duty cycle.

A change in any of these parameters will affect the expected life of the relay. For example, a reduction of the temperature by 50 °C can double the life expectancy of the contacts. Similarly, a reduction of the cycling rate or the ratio of on-time to off-time will have some effect on increasing the life expectancy.

The distinctive types of loads are:

- a. Resistive loads. The basic resistive load given for each relay on the individual spec sheets forms the base line rating for the relay. If the relay is tested under the conditions of MIL-R-6106 or MIL-R-39016 at the specified rating, it will perform under the rated load conditions for a minimum of 100,000 operations. Thus, the ratings and life expectancy figures do not represent the point at which the relay may be expected to fail, but represent the minimum number of operations at rated load which the relay can be expected to perform with high confidence levels.
- b. Inductive and motor loads. When the current to a dc inductive load is broken by the relay contact, the collapse of the magnetic field of the inductor or will induce a short-lived transient voltage which may be severe enough to cause considerable arcing.

The severity of this effect will depend upon the L over R ratio of the load, the normal operating current, and the speed with which the contact opens. Generally, such loads as circuit breaker coils, solenoids, or stalled dc motors provide high load currents and high L over R ratios, and will generate an arc sufficient to permanently damage or destroy a pair of contacts. The arc generated by this type of inductive load also serves to generate severe radio-frequency interference.

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The use of relay contacts, to break the inductive load of a second relay coil, will induce a high transient voltage even when the second relay coil is properly suppressed. For example, assume the contacts are switching a 28-Vdc line to a second relay coil which is suppressed to 42 V. The contacts will see the supply line of 28 V plus the 42-V transient of the coil during switching. The effective voltage of 70 V appears across the relay contacts during turn off of the second relay. Because most of the referenced military specifications rate the contacts at 28 Vdc, the load shown in this example exceeds the capability of the contacts, resulting in excessive arcing, shortened life, and potential failure. The effect of switching on unsuppressed coil could be catastrophic with surge voltage levels up to 1500 V.

Since each inductive load has its own time constant characteristics (its own L over R ratio) and its own load currents of a steady state nature, it is virtually impossible to establish a fixed inductive rating for each type of relay, which would be meaningful to the user. In general, however, the inductive load rating for any inductor of significance would be less than 50 percent of the normal resistive rating for the relay. There are two practical approaches to the solution of this problem, as follows:

1. Transient suppression of the load is recommended wherever possible. If proper suppression is utilized, the normal resistive ratings of the relay can be used, simplifying the acceptance testing procedure and the qualification-testing procedures necessary for the part. In addition, proper suppression provides protection against generation of radio-frequency noise, since the contact arc has been reduced considerably. For several typical suppression circuits, refer to the circuits shown in Figures 3 through 5 of this section.
 2. Consultation with the components engineer with knowledge of the specific load requirements will help in the selection of the proper relay for switching the load. When a relay has been selected, it should be tested under actual load conditions to insure that it will perform the function properly.
- c. Current loads. Between rated load conditions, as discussed above, and dry circuit contact loads, discussed later in this section, lies a vast region in which most contact applications fall. That portion of the contact load area falling between approximately 25 to 500 mA can generally be considered to be in the intermediate current area. It would normally be expected that contacts rated at 2 A, 30 Vdc would operate perfectly well in the intermediate current area. Such is not always the case. The relay may very well switch the load without any catastrophic failure of the contact system, but the failure criteria of contact resistance, if used, may very quickly fail the relay under intermediate current conditions.

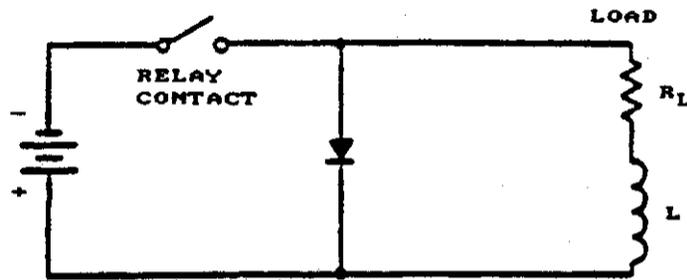


FIGURE 3. Diode arc suppression.

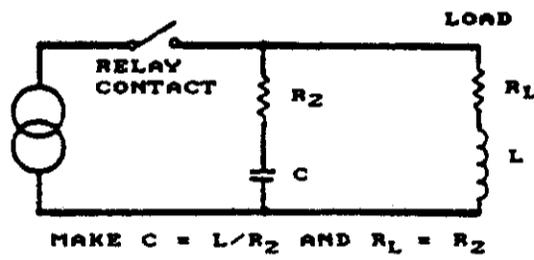


FIGURE 4. RC arc suppression.

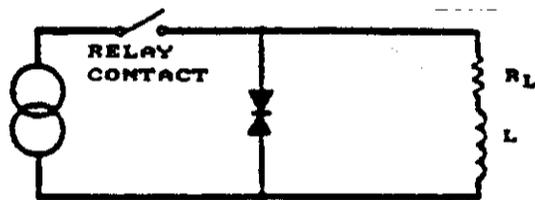


FIGURE 5. Diode arc suppression, ac.

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Under rated load conditions, the current density and arcing that occur at the contact surface are sufficient to provide a constant cleaning or burnishing action, keeping the contacts free of insulating contaminants which may be formed. In the case of low level circuit applications, the voltage and current levels are extremely low, and no arcing occurs.

In the case of the intermediate current application, the current density in the contact area will be sufficient to aggravate normal galling actions and to carbonize any hydrocarbons that may exist in a gaseous condition within the relay with any residues, developing deposits in and about the contact area. The result is that the relay will exhibit contact resistance which is out of specification under intermediate current load conditions, although failure of the relay to switch the prescribed load may not necessarily be impaired, and, in fact, is a condition which rarely occurs.

In the event that higher than normal contact resistance is a problem in the application of the relay in the intermediate current area, care should be exercised by the specifying engineer to inform the manufacturer that such is the case. This condition can be minimized or eliminated by proper controls of the manufacturing techniques, usually involving more critical handling and manufacturing methods, and additional precautions in the selection of materials utilized in the relay construction. Thus, for a relay designed specifically for low contact resistance in the intermediate current area, the basic cost is usually higher than for a standard production line unit.

- d. Low-level loads. Low-level loads are generally those which are in the millivolt and microampere region. The common military specifications (MIL-R-6106 and MIL-R-39016) have established 6 Vdc and 10 mA as maximum values for testing purposes. With voltages and currents of this value or less, there is insufficient voltage to break through a barrier film and insufficient current to produce an arc that might cleanse the contact area. For this reason, the contacts of the relay are of a noble metal (usually gold) to avoid corrosion, and are manufactured to maintain optimum cleanliness. The softness and inertness of gold reduces the susceptibility to and maintenance of film contamination.

For relays to be utilized in low-level applications, it has become common practice for the design engineer to specify the usage, and for the manufacturers of the relays to provide for a 5- or 10-thousand operation run-in miss test, with all contacts monitored. A test of this nature provides data on the ability of the relay to perform its low-level function, eliminates the infant mortality failures, and provides reliability assurance on the particular production lots in question. Relays which are to be used in low-level applications should not be used or tested at higher currents prior to usage in low-level applications.

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- e. Dry-circuit loads. Dry-circuit loads are applications in which the relay contact does not make or break the current. The contacts are closed before the power is applied through the contacts. Power is always removed before the contacts are opened. The contact may be any value within the specified rating, as the contact does not make or break the load current. There is no arcing to cause erosion of the contact surface. The life of the contacts used in dry circuit applications approaches the mechanical life of the relay. Contacts are normally plated with noble metal to avoid corrosion or oxide formation.
- f. Lamp loads. A tungsten filament lamp has the characteristic that when cold, it has a much lower resistance than when incandescent. Therefore, contacts which are used to switch lamp loads will see a surge current (inrush current) which may be 3 to 10 times the steady state current of the lamp. For most applications this is not too severe, since most of the lamp loads encountered are of the small miniature types. However, a lamp with a steady state current near the rated current of relay should be used with caution, since there is a possibility that the inrush current will weld the contacts. In the event that this may be a problem, a small series resistor may be used with the lamp to limit the inrush current. The use of series resistor has an additional benefit as it reduces the lamp voltage, thereby extending lamp life.
- g. Capacitive load. A capacitive load has the characteristic of a short circuit through the contacts for a short duration, depending on the size of the capacitor and the series resistance. Although the time interval may be as low as a few microseconds, sufficient current passes through the contacts to permanently damage or weld them. The practical solution to this type of load is to add sufficient series resistance to limit the inrush current to an acceptable level.
- h. Contact load and life curves. The life versus load curve shown in Figure 2 is the result of many hundreds of relays being tested under a variety of load conditions. Because the curve is intended to cover a broad spectrum of relay types, it has been very conservatively drawn, and can be referred to in establishing the resistive contact ratings for any of the MIL-R-5757, MIL-R-6106, or MIL-R-39016 relays. This curve does not specifically refer to low-level contact life, which must be considered under the special conditions of extremely clean contacts for the life of the relay.
- i. Contact arc suppression. To avoid damage to contacts when the load has an inductive component, one of several methods of arc suppression should be used. For dc loads, a simple diode may be employed as shown in Figure 3. The diode must be able to pass a current equal to the normal load current, and should have an inverse voltage rating higher

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than the source voltage of the circuit. For ac circuits, two methods are available. One is to make the load impedance appear resistive by the use of a series RC circuit in parallel with the load. (Refer to paragraph 17.1.4.3 of this section for equations calculating the values of R and C). The second method is by the use of special ac diode suppression available commercially. Figure 4 illustrates the resistive load principle, good for any frequency of operation, and Figure 5 shows the application of diodes, which must withstand load current and voltage. These devices should be separate components and not built into the relay. The use of additional components inside the package reduces reliability though particle contamination, outgassing characteristics, and the additional failure rate of the added parts.

17.1.5 General guides and charts. The effects of ambient temperature on relay performance is often overlooked. Because of the change in winding resistance with temperature, the force available to operate the armature decreases with increasing temperature. Figures 6 and 7 show this effect.

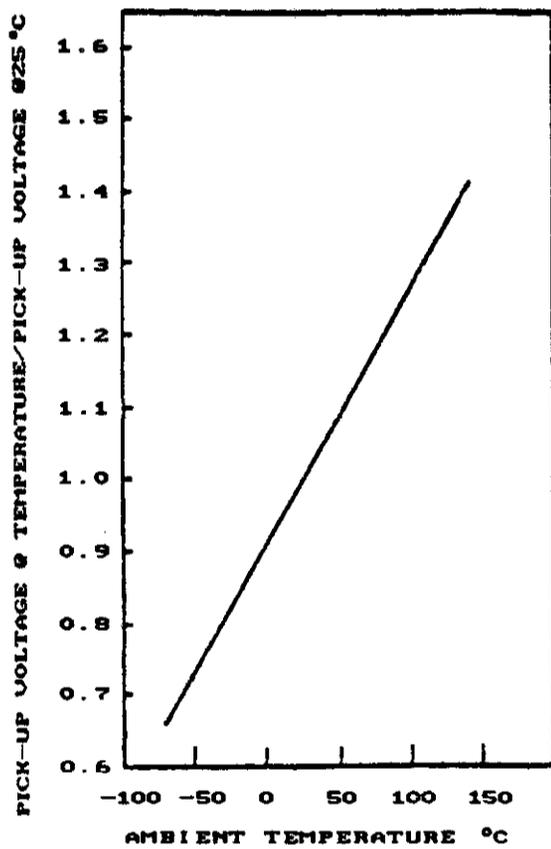


FIGURE 6. Pickup voltage vs temperature.

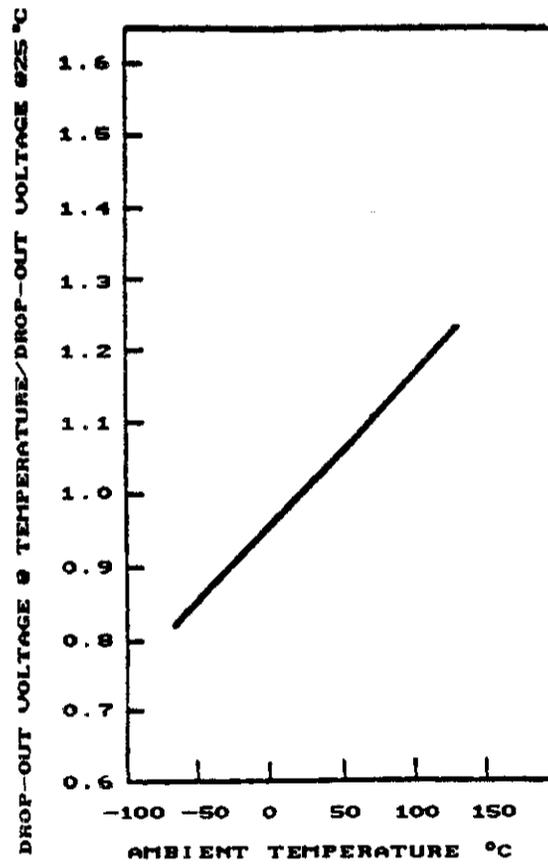


FIGURE 7. Dropout voltage vs temperature.

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17.1.6 General reliability considerations. Relays are electromechanical devices and are subject to both electrical and mechanical failure. Some causes of failures are poor contact alignment, loss of resiliency in springs, and open coils, as well as open, contaminated, or pitted contacts. Contact failure can result from high inrush or sustained high current, or from high voltage spikes when an inductive circuit is opened. High inrush currents occur in loads composed of motors, lamps, heaters, capacitive input filters, or other devices that have low starting resistance compared to operating resistance. These currents may cause intense heat with associated welding of the contacts.

In addition to overstressed contacts, contamination is the most common cause of relay failure. It is a particularly annoying cause of failure because it is often intermittent and difficult to verify. This may be nonmetallic or gaseous contamination, which periodically deposits itself on the contacts, causing an open condition; or metallic particles which cause shorted conditions or block movement of the mechanical parts. This cause of failure can be significantly reduced by process controls, use of welded hermetic sealed enclosures, small particle cleaning, assembly and back filling in Class 100 clean room facilities, as defined in FED-STD-209 precap visual inspection, and added screening after assembly.

There have been a number of failures attributed to vendor workmanship. Timely corrective action by the vendor has significantly reduced this type of failure.

Engineering selection of the proper relay for an application is the most significant factor of relay reliability.

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17.2 RELAYS, ARMATURES

17.2 Armatures.

17.2.1 Introduction. Armature relay operation depends upon energizing an electromagnet which attracts a hinged or pivoted lever of magnetic material to a fixed pole piece. The hinged or pivoted lever is called the armature. Another style, sometimes erroneously called a rotary relay, is pivoted between two pole pieces and the magnetic circuit contains two airgaps. Although the motion of the armature is circular, the relay is still basically an armature type. If necessary, a delay may be introduced into either the operating time, the release time, or both. This is discussed in subsection 17.4 Time delay. MIL-STD-975 includes armature relays in accordance with MIL-R-39016 for Grade 2 application.

17.2.1.1 Applicable military specifications.

MIL-R-5757	Relay, Electromagnetic
MIL-R-6106	Relay, Electromagnetic [Including Established Reliability (ER)]
MIL-R-28776	Relay, Hybrid, Established Reliability
MIL-R-39016	Relay, Electromagnetic, Established Reliability

Only MIL-R-39016 is included in MIL-STD-975.

17.2.2 Usual applications. Relays may be used in any of the following applications:

- a. To obtain isolation between the input circuit and the output circuit
- b. To invert the signal sense (from open to closed and vice versa)
- c. To increase the number of output circuits (so as to switch more than one load or to switch loads from different sources)
- d. To repeat signals
- e. To switch loads of different voltage or current ratings
- f. To retain an input signal
- g. To interlock circuits
- h. To provide remote control.

Proper application of relays requires consideration of characteristics such as input power or current available, the contact arrangements and load requirements which must be met, as well as size limitations and all other electrical, physical, and environmental characteristics which the relay must meet. If general understanding of the varieties of individual relay characteristics

17.2 RELAYS, ARMATURES

is possessed, it is possible to optimize a given characteristic which may be important in a given circuit. The military requirements are stated at a specific set or sets of conditions. For applications which vary from the specified conditions, the expected performance capability of the relays must be controlled by specification.

17.2.2.1 Misapplications. The following, extracted from MIL-STD-1346, discusses potential misapplications of relays.

- a. Improperly using existing military specifications by erroneous interpretation or even using the incorrect specification altogether. A given set or sets of conditions are provided in the specifications. Variations from these conditions will affect performance of the relay accordingly.
- b. Paralleling contacts to increase capacity. Contacts will not make or break simultaneously, and one contact carries all the load under the worst conditions. Contacts can be paralleled for added reliability in the low level or minimum current (contamination test current) areas.
- c. Circuit transient surges. Circuit designers must be careful not to expect relays to handle circuit transient surges in excess of their ratings.
- d. Using relays under load conditions for which ratings have not been established. Contact ratings should be established for each type of load. Many relays will work from low level to rated load, however, the designer should not expect such performance.
- e. Using relays on higher voltages than those for which they were designed; for example, switching 300 V power supplies with relays only rated for 115 V maximum.
- f. Contact ratings with grounded case. Relays switching 115 Vac with a grounded case must have the contact ratings significantly lower than in the ungrounded case mode of operation. The maximum ac rating of a nominally rated 28 Vdc, 2 A resistive relay is of the order of 0.300 A. Switching the ac loads with the relay case ungrounded results in a potential hazard to personnel.
- g. Transferring the load between unsynchronized power supplies with inadequately rated contacts. When the load is switched, the voltage amplitude can range from in phase to 180 degrees out of phase; therefore, the relay contact voltage may vary from zero volts to two times peak voltage and maximum current.
- h. Switching polyphase circuits with relays tested and rated for single phase only. A typical misapplication is the use of small multipole relays (whose individual contacts are rated for 115 V single-phase ac

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17.2 RELAYS, ARMATURES

in 115/220 V three phase ac applications. Phase-to-phase shorting at rated loads is a strong possibility in these instances, with potentially catastrophic results.

- i. Using relays with no established motor ratings to switch motor loads. In addition, caution should be used in applying relays to provide braking by reversing a motor, particularly where the motor can be reversed while running, commonly called plugging. This results in a condition where both voltage and current greatly exceed normal.

Many power relays should not be utilized in potential plugging situations unless so rated by the manufacturer.

- j. Using relays with no established minimum current capabilities. It must not be assumed that because a relay is used in an application considerably below its rated contact load that the consideration of a minimum current capability can be ignored; this is especially true if there is no established level of minimum current for the relay.
- k. Using relays rated for 115 Vac only on 28 Vdc or higher voltage dc applications. If contacts in these devices are of the single break form-A type, it may be necessary to derate severely for use on dc applications using 28 V or higher.
- l. Using relays at coil voltages below rated coil voltage. The operational parameters, life characteristics, and ability to withstand dynamic environments are based on operation at rated coil voltages. Reducing the coil voltage may extend time to operate, reduce contact closure forces, reduce holding force, increase arc duration, and reduce ability to operate properly during vibration or shock, or may preclude the relay from operating at all.
- m. Using relays when the coil is driven by a slowly rising power supply. The relay operates during some point during the increase in driving current from the power supply. Back electromotive forces (EMF) are produced when the armature closes to the pole face. The back EMF is the opposite polarity to the driving voltage causing the relay to release and then reoperate when the drive current increases to a sufficient level to overcome the back EMF.

17.2.3 Physical construction and mechanical considerations. Mechanical considerations briefly discussed in this section are size and shape, weight, terminals, method of mounting and contact arrangement. Physical construction is briefly discussed in paragraph 17.1.4 General parameter information.

Relays are constantly being made smaller, as are other component devices. Very complex relay devices are now available in a TO-5 transistor package. Ratings in this size vary up to 1 A. Other miniature sizes available with higher ratings include the crystal can series. They range from one-sixth crystal can size to full-size crystal can. The above devices are available as military standards with qualified suppliers.

17.2 RELAYS, ARMATURES

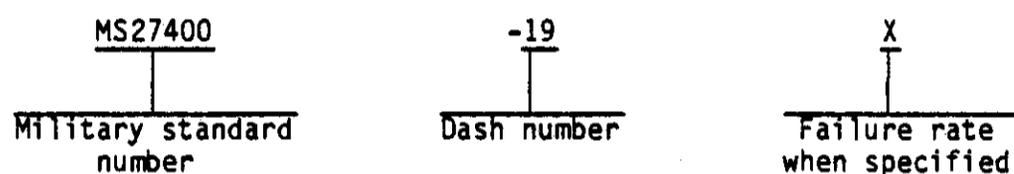
The most common terminals supplied with relays are screw, solder, plug-in, printed-circuit and quick-connect. Military applications usually require the solder, plug-in, or printed circuit type.

Hermetic sealing of relays used for military applications is generally required. MIL-R-5757, MIL-R-6106, MIL-R-28776, and MIL-R-39016 now require that cases be of welded construction. Previously soldered units were somewhat susceptible to interior contamination. Welding will increase the reliability of the hermetically sealed units.

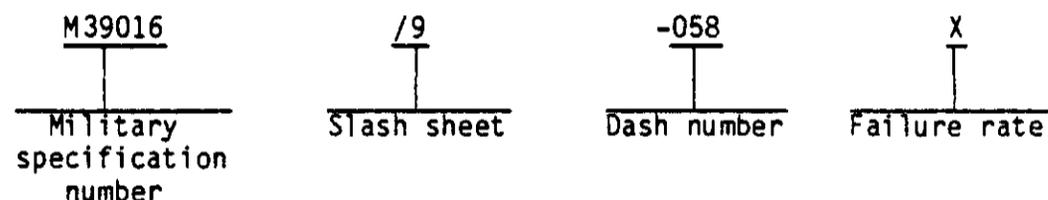
Figure 8 shows the internal construction of a typical armature relay with an associated parts list.

17.2.4 Military designation. Two methods of specifying relays are as follows:

a. Military standard



b. Military specification (only MIL-R-39016 is included in MIL-STD-975)



MIL-R-5757 is the general military specification for electrical relays with contact ratings up to and including 10 A. However, this specification is now being replaced by MIL-R-39016. As rapidly as sources become qualified for MIL-R-39016, they will replace equivalent MIL-R-5757 parts. Many styles, shapes, and sizes are available.

MIL-R-6106 is the general military specification for electrical relays for use in aerospace systems. They are capable of being mounted directly to the aircraft, missile, or spacecraft, and the relays are available in a wide range of contact ratings up to 400 A. The method of specifying these relays is by military standard reference or military specification number as appropriate.

MIL-R-28776 is the combination of a solid state input element functioning with an established reliability electromechanical relay that is hermetically sealed. The method of specifying these relays is by military specification number.

MIL-R-39016 is the general military specification for established reliability electromagnetic, hermetically sealed relays. These relays are designed to operate in low and medium power switching circuits with contact ratings up to 10 A.

17.2 RELAYS, ARMATURES

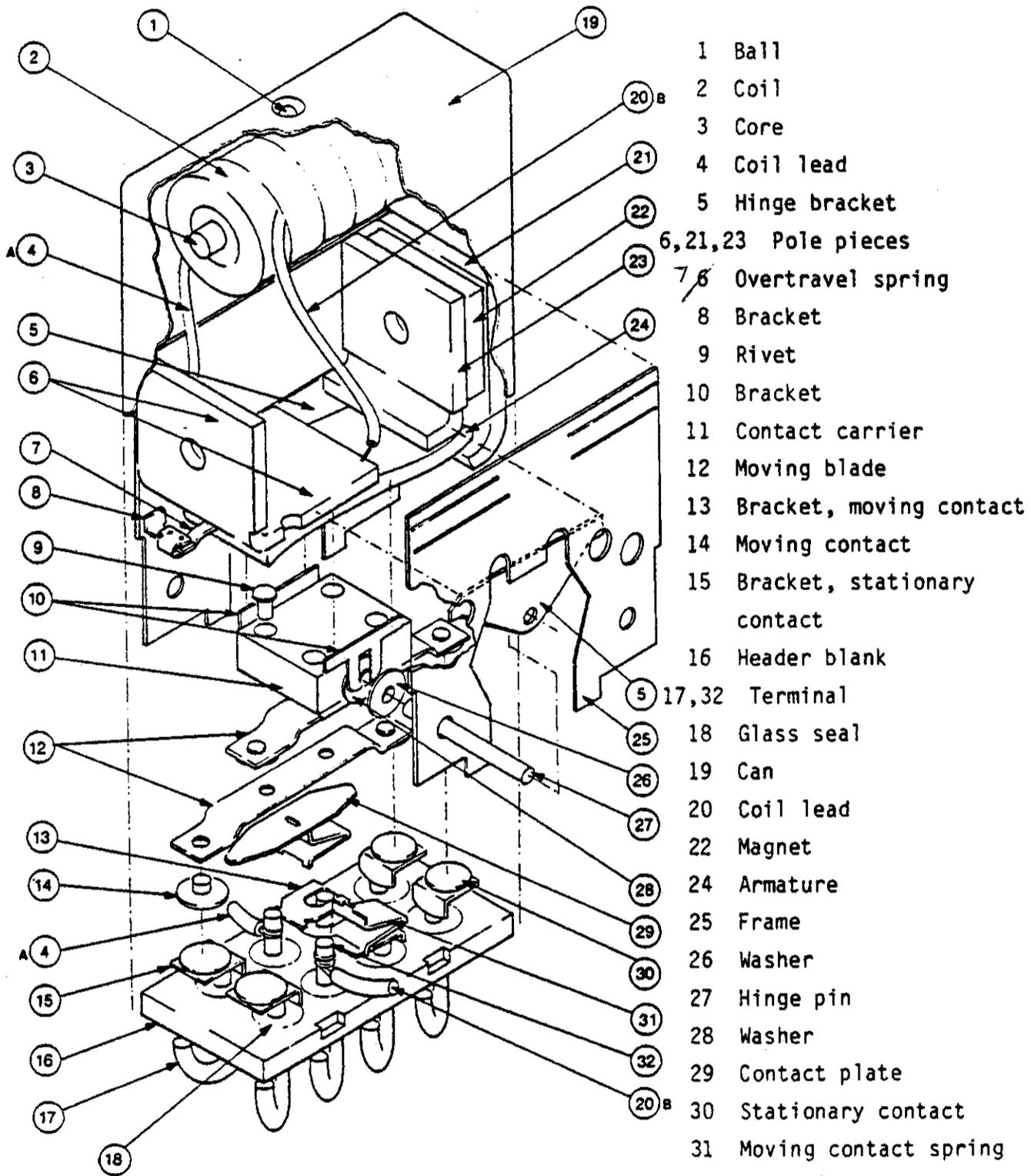


FIGURE 8. Typical armature relay.

17.2 RELAYS, ARMATURES

17.2.5 Electrical characteristics. The primary electrical considerations in selecting a relay are contact rating and coil voltage. Secondary considerations should be type of voltage (ac or dc), frequency (ac coils or load), thermal effects, types of loads (high power, intermediate, low level, inductive, motor, lamp, etc.), cycle rate, duty cycle, and transients. Each of these topics are covered in paragraph 17.1.4.

17.2.6 Environmental considerations. The environmental effects on relay operation are frequently overlooked during initial relay selection and application. While the basic temperature range of the relay is always considered, the effect of self heating from the coil and the IR heating across the contacts is often neglected. This increase in temperature is discussed in paragraph 17.1.4, as it affects operational parameters.

The dynamic environments of vibration and shock are the parameters where relays are frequently misapplied. Although the input levels of these environments are known and taken into account during selection, the amplification by a non-rigid mounting surface is often forgotten. When relays are mounted on an unsupported portion of a circuit board or structural surface it is not unusual to measure vibration levels 5 to 10 times higher than the input vibration level.

17.2.7 Reliability considerations. Paragraph 17.1.7 which was concerned with reliability failure data in general should be consulted for reliability and failure mode data.

Relays contained in the military specifications MIL-R-28776 and MIL-R-39016 for established reliability relays demonstrate a failure rate level of 0.01 to 3.0 percent in 10,000 relay operations at confidence levels of 90 percent for qualification and 60 percent for maintenance of qualification. Relays in military specification MIL-R-6106 that are identified as established reliability relays demonstrate a failure rate level of 0.1 to 1.0 percent in 10,000 relay operations at confidence level of 90 percent for qualification and 60 percent for maintenance of qualification.

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17.3 RELAYS, REED

17.3 Reed.

17.3.1 Introduction. The high speed, reduced potential for contamination, and limited number of moving parts of a reed relay provide industry with a bridge between electromechanical relays and solid-state switching devices.

The major component of a reed relay is the reed capsule commonly known as a reed switch. The switch is part of the magnetic circuit and the contact path of the relay, and it embodies the operating and switching parameters. Successful operation of a reed relay in a circuit will almost entirely depend on proper selection of the reed switch and close adherence to the switch specifications.

These devices are not included in MIL-STD-975.

17.3.1.1 Applicable military specification.

MIL-R-5757	Relay, Electromagnetic
MIL-R-83407	Relay Reed, Mercury Wetting
MIL-R-83516	Relay, Reed, Dry

17.3.2 Usual applications. Long electrical life of precious-metal contacts sealed in an inert atmosphere, the absence of wearing mechanical parts, immunity from circuit noise, high circuit isolation, and fast switching speed are the most significant features of reed relays. The small size is adaptable to high-density, printed-circuit-card mounting applications. Low price and a wide variety of contact forms and package configurations encourage use of reed relays in almost all types of circuit applications. Operating speed, under 2 ms, is acceptable for most control systems where the end function is operation of electromechanical devices. Commercial devices, test equipment, and numerous telephone circuits use reed relays.

The various types of reed relays described herein indicate the great versatility of both contact switching capabilities and types of packaging. The unique features of reed relays have caused it to be widely accepted for many types of circuit switching; therefore, the idea of selecting a reed relay to fill all types of switching applications may be very enticing. However, the specific application should still determine the style and type of switching method best suited for a particular designer's requirement.

For example, if complete sealing of the contact switching members and switching speeds in the millisecond range is not needed, a general purpose electromagnetic type relay may well be the most economical choice for multiple pole switching. If closed circuit resistance in the fractional ohm range and open circuit resistance in the multiple megohm range is not needed, but extremely fast switch-speed is needed, a solid state type of switch may be the best choice. The circuit designer should, therefore, consider the various parameters needed for a particular application and attempt to choose the component which is most suitable.

17.3 RELAYS, REED

17.3.3 Physical construction and mechanical characteristics.

17.3.3.1 Construction. The basic reed switch consists of two overlapping, flat, ferromagnetic reeds separated by an air gap, and sealed in a glass tube as shown in Figure 9. The reeds are sealed, one at each end of the tube, so that their free ends overlap in the center of the tube. During the sealing operation, dry nitrogen gas is forced into the tube, creating an inert atmosphere for the contacts. When the switch is introduced into a magnetic field, the reeds become flux carriers, and the overlapping ends become opposite magnetic poles which attract each other. If the magnetic attraction between the reed ends becomes strong enough to overcome the stiffness of the reeds, they move together and touch, completing the magnetic circuit and making electrical contact.



FIGURE 9. Reed switch (NO) construction.

To obtain a low and consistent contact resistance, the overlapping ends of the reeds are precious-metal plated, typically with gold, rhodium, ruthenium, or a combination of these. This plating not only affects the switch's electrical characteristics but also acts as a residual gap and largely determines the release point. The plating must be thin and uniform to ensure that the magnetic properties of the switch are not adversely affected. Plating which is too thick causes the switch to have a high or inconsistent contact resistance and a high release point. Contact resistance depends on the plated contact surface and the contact pressure. Contact pressure is dependent upon the attractive force between the reed ends. The force is a function of the flux density in the gap and is controlled by the size of the reeds, the gap, and the amount of overlap. These factors thus establish the operate characteristics of the switch. All parameters must be rigidly controlled to ensure the consistent operate and release points necessary for using reed switches in relays.

Mercury reed switches are available for applications where contact bounce cannot be tolerated. In this switch, one reed is wetted with mercury which is fed to the contact area by capillary action from a pool at the bottom of the switch. The mercury forms a fluid contact which eliminates bounce and provides a low and consistent contact resistance throughout the life of the switch. Mercury reed switches are suitable for ground based equipment only, since mounting must be maintained in a specified position and under normal gravitational forces.

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The basic reed switch has a normally open, Form A, contact. A normally closed, Form B, contact is made by biasing the normally open contact with a permanent magnet or by mechanically biasing one reed. A Form C contact is made by combining a Form A and a Form B in the same capsule. These contacts have the same ratings as the normally open switches.

Single-capsule Form C reed switches are available in many configurations which can be grouped into two main categories:

- a. Reed switches that use a magnetic bias to close one set of contacts
- b. Reed switches that use a mechanical bias to close one set of contacts

17.3.3.2 Mercury-wetted, 1 form D mechanically biased. Utilizing the characteristics of the mercury-wetted, 1 form C contacts and reducing the air gap, a make-before-break action can be achieved. Figure 10 shows the action of mercury wetted 1 form D contacts changing from the normally closed position, Figure 10A through intermediate positions, Figures 10B and 10C, to rupture of the mercury surface, Figure 10D, and the final state of normally open contacts closed, Figure 10E.

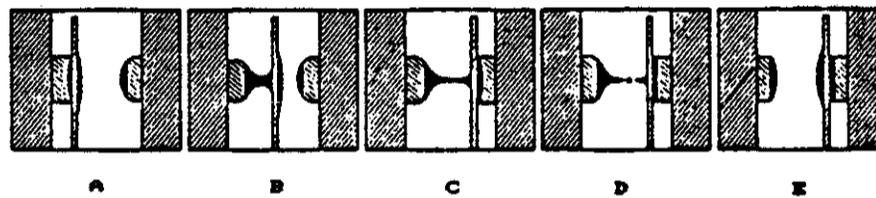


FIGURE 10. Mercury-wetted contact action 1 form D.

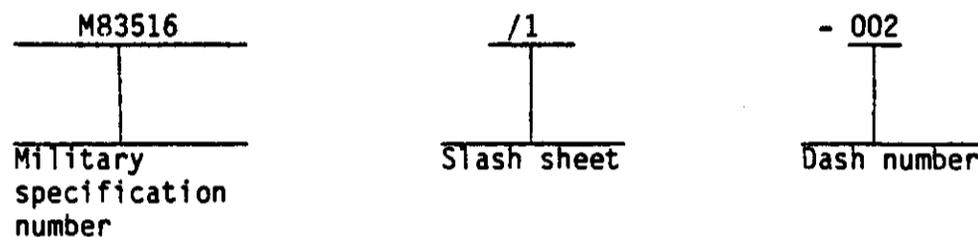
17.3.3.3 Latching relay. Multiple-wound coils are available for a variety of special applications such as logic gates, flip-flops, code-checking relays, and latching or bistable relays. The latching relay, one of the most common special assemblies, consists of a bifilar coil (two windings simultaneously wound on the bobbin), a magnet, and a reed switch. The magnet is strong enough to hold the reed switch closed once it operates, but cannot close the switch without the aid of a coil. A pulse to one winding, aiding the magnet, closes the reed switch, which is then held closed by the magnet. A pulse to the other winding, opposing the magnet, causes the switch to open. The major advantages of the latching relay are its speed, low operate power, and memory without power.

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17.3 RELAYS, REED

17.3.3.4 Relay packages. Reed relays are available in many different configurations to meet standard and special packaging and environmental requirements. Often space dictates which style assembly to use. The low-profile reed-relay package for printed-circuit-card mounting offers the greatest density and convenience.

17.3.4 Military designation. MIL-R-5757, MIL-R-83407, and MIL-R-83516 are the general military specifications for reed relays. Shown below is the proper method of specifying a military designation.



17.3.5 Circuit considerations. To obtain the best performance from reed relays in a circuit, the following points should be considered:

- a. The load to be switched should not exceed the switch rating. Inductive loads must be suppressed, and high inrush loads, such as lamps, should be current-limited.
- b. Although close-tolerance power supplies are not required for reed relays, there must be enough safety factor in the supply to ensure proper operation in spite of adverse temperature and voltage conditions.
- c. Control-pulse waveforms from limit switches and other similar devices must be free of bounce. The speed of the reed relay enables it to follow the discontinuities of some of the most commonly used input switches. Inputs to reed counters or registers should be buffered by devices such as mercury-wetted contact relays, that do not generate bounce.
- d. Whenever possible, the reed switch should not be used to switch loads. Using the reeds to establish a path and then switching the load from a single heavy-duty contact can add millions of operations to the life of the reeds.
- e. Because the reeds will resonate at their natural frequency of approximately 1000 Hz, a sufficient off time should be allowed before re-applying a holding voltage to prevent false reclosure. Dimpled reed switches, which mechanically damp the oscillation, may be used when the application does not permit sufficient off time.

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17.3.5.1 Basic contact forms. The basic contact forms used with reed and mercury wetted contacts are Form A, Form B, and Form C. The Form C contact symbol usually refers to a single-pole, double-throw contact with a break-before-make contact switching action. In certain types of mercury-wetted reed relays, Form D make-before-break contacts are available. It has become conventional to show these with the same symbol as the Form C contact, while in more typical relay nomenclature, a different symbol is indicated.

Reed switches are normally available with a single contact form enclosed in an individual glass envelope. The various types of basic switches have been described in paragraph 17.3.3 Physical construction. Multiple contacts are not available within a single glass switch.

17.3.5.2 Contact rating. The most commonly used contact materials for reed switches are gold, rhodium, and various proprietary alloys. These switches are also available with silver, tungsten, of a variety of precious metal contacts. Careful choice of the particular contact material can definitely give optimum life for a given load.

The contact ratings for reed and mercury-wetted contact relays are to be considered as definitely maximum values. Not only must the maximum current and voltage be considered, but the volt-ampere rating, the product of the maximum current and voltage at the time of switching, must also be considered. If a given relay is operated at lower levels than maximum contact rating, extended life can normally be expected. For example, the contact rating of a standard single-pole, double-throw switch used on relays is rated at 10 V-A at 0.5 A maximum, or 250 V maximum, resistive load. At this maximum rating, a typical life expectancy would be 25 million operations. At approximately half this rating, the life expectancy would be 50 million operations. At a relatively low contact level, the life expectancy could well exceed 100 million operations.

Contact life cannot be derated by the use of heavier contact switching. With non-reed relays, it is very common to have derated life with overload switching conditions. For example, a conventional relay with 5-A contacts may have a life expectancy of approximately 300,000 operations at 5 A. At a level of 7 or 8 A, the typical life expectancy might well be 100,000 operations. In the case of reed relays, the maximum contact ratings indicated should definitely be considered a maximum and should not be exceeded in either the steady state or transient switching condition.

In order to obtain maximum contact life, it is necessary that any transient voltages or currents be kept within the maximum specified. In any case, appropriate arc suppression will always yield longer contact switching life.

17.3.5.3 Contact resistance. The apparent contact resistance which appears at the terminals when measured at very low levels of current and voltage can deviate considerably from given values. This is an inherent characteristic of any metallic contact and must be considered when using low level circuits.

17.3 RELAYS, REED

The contact ratings of all types of reed relays should be taken to indicate the maximum value, at the time of switching of the current, voltage, and the volt-amperes. These values should not be exceeded in either the steady state or transient conditions. Therefore, in circuits where transient conditions can exist, the use of arc suppression or quenching is necessary. To obtain maximum life under any switching conditions, arc suppression is recommended.

Various types of arc suppression are commonly used, the more typical types being diodes, resistor-capacitor networks, zener diodes, nonlinear voltage sensing resistors which exhibit high impedance to low voltages and low impedance to high voltages, and certain special devices designed specifically for arc suppression. The choice of type of arc suppression, and the particular values to use, depend upon the specific application involved. These transient conditions should be considered in all cases, and appropriate arc suppression used when necessary. The manufacturer of a reed relay can commonly give rules of thumb for a specific product, but it is very difficult to generalize on the proper type of arc suppression which would cover most cases. Additional information is contained in paragraph 17.1.4.

17.3.6 Environmental considerations. Reed and mercury-wetted relays are normally ideal types of devices for operation in adverse environmental conditions, as the contact switching elements themselves are hermetically sealed. However, depending upon the environmental conditions, consideration must be given to the packaging to obtain the greatest reliability. For extremely adverse conditions, completely hermetically sealed relays, or similar constructions are recommended.

Special consideration must be given to mounting limitations on mercury-wetted relays as they are normally position and gravity sensitive.

There is a low operating temperature limitation on mercury wetted relays. The limitation is due to the freezing point of mercury (-38.8 °C), and it must be considered for all applications.

The life of a relay is ordinarily limited by mechanical wear and electrical erosion of the contacts. As the contacts are in a closely controlled atmosphere, any deterioration due to atmospheric conditions is not possible with reed switches. Therefore, the contacts themselves are able to withstand extremely adverse environmental conditions such as humidity, low pressure due to high altitudes, salt spray, and so on. The only limitations are due to the mechanical construction of the external parts of the reed leads, or the external relay structure. The external magnetic reed members are either plated, electro-tinned, or hot tin dipped to allow ease of solderability to relay terminals.

In the mercury-wetted contact switch, suitable for ground applications only, the film of mercury provides an almost ideal contact surface. Contact resistance is constant, regardless of low-level, nearly zero current and voltage,

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17.3 RELAYS, REED

or full-capacity loads. The mercury film cannot be squeezed off the contacts, and any mercury lost from the contacts is quickly replaced by the built-in wick action. In the normal production process, a mercury-wetted contact relay is operated millions of times to insure uniformity and stability. Erosion of the metal contact surfaces by the mercury is negligible. There is little change in the character of the armature and contacts because of the limited motion. Life is rated in billions of error-free operations.

Two factors which must be considered in all relay packages are reed mounting and magnetic shielding. Reed switches should be mounted so that stress is not transmitted to the seal area. Stress can cause the seals to fracture in handling, resulting in early contact failure. Although shielding is not required to make the relay operate, it does improve power sensitivity and reduce the effects of magnetic interaction with adjacent relays.

17.3 RELAYS, REED

17.3.5.4 Operate and release time. In general, the smaller the relay the faster the operating time. For fastest possible operating speeds, the micro-miniature types are recommended. The standard-size switches are typically slower than the miniature or microminiature types.

Faster operating speeds can normally be obtained by the selection of a minimum ampere-turn pull-in reed and can be available by a sorting process. For the fastest possible operating speeds, the use of series resistance and higher applied voltages will yield the best conditions. For example, a standard miniature Form A relay will have an average operate time of approximately 1 millisecond. If a resistor, having resistance equal to the coil resistance, is put in series with a relay, and a voltage of twice the coil nominal voltage is applied to the complete circuit, a reduction in operate time can be obtained. The greater the series resistance and the higher the overdrive voltage, the faster the operate time. However, an absolute minimum operating time occurs on all types of relays regardless of driving conditions.

Dropout times are based on the relay being operated at nominal voltage at room temperature, and the circuit opened through use of a high impedance contact switch of some type. This time also is based on no other series or parallel elements being connected to the coil circuit. Because diodes and similar devices are commonly used across relay coils for arc suppression of preceding contacts, it must be remembered that the use of these elements can appreciably delay the dropout time of the relay.

17.3.5.5 Contact bounce. All types of solid metallic contacts normally exhibit some contact bounce. This is true of reed relays as well as conventional general purpose relays. This contact bounce is normally caused by impingement of the mating contacts. In general, the contact bounce of a normally open contact on operation of the relay is considerably less than the contact bounce of a normally closed contact on the release of the relay.

In the circuits where absolutely no contact bounce is permitted, the use of a mercury-wetted reed relay or mercury-wetted contact relay is required. These types of relays will switch contacts with absolutely no bounce if the unit is properly constructed mechanically and has the proper magnetic biasing. The contact interfaces, which are covered with a film of liquid mercury, absorb the shock of operation, and the contacts will not open electrically, but remain closed after initial closing.

Note that mercury wetted relays must be mounted as specified and are thus suitable for ground based equipment only, as they are sensitive to the effects of gravity.

17.3.5.6 Insulation resistance. In the manufacture of the basic reed switch, the parts are carefully cleaned and assembled under closely controlled conditions, and the unit is filled with an inert gas. Because of this, the insulation resistance of the basic reed switch is quite high. The insulation resis-

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tance across open contacts is typically $10^{11} \Omega$ or greater. During normal manufacture and handling, and when the reed switch is built into an assembly, various parallel insulation paths are established. Therefore, the insulation resistance of a reed relay, measured at the terminals, can be expected to be lower than that which is obtained on the basic reed switch. For many types of relays a typical insulation resistance of $10^9 \Omega$, or greater, can be expected. However, as this parameter is not normally tested on a 100 percent basis, it is recommended that when leakage can be a problem in a given circuit, the required insulation resistance should be specified. By the use of proper insulating materials and closely controlled manufacturing techniques, many of the standard types of relays can be obtained with insulation resistance as high as $10^{12} \Omega$. This figure would represent measurements made on a clean relay at normal room temperature and humidity. If, subsequently, the relay is subjected to dust or dirt, or to high humidity conditions, insulation resistance measurements lower than this would be expected.

17.3.5.7 Contact capacitance. As the reed leads present parallel metallic surfaces at the contacting end in their open position, a measurable capacitance across the contacts is obtained on any type of reed relay. In addition, measurable capacitance is also obtained from the coil to the reed leads. Depending upon the type of mechanical construction and size of the unit, capacitances from approximately 0.5 pF to 5.0 pF are obtained across open contacts. With a given relay construction, the capacitance between open contacts and the coil, with the relay not energized, is usually about twice the value of the open contact capacitance. With the contacts closed and the coil energized, the capacitance from contacts to coil is about four times the value of the open contact capacitance. These are general "rules of thumb" and if inter-capacitance coupling is important in a given application, it is recommended that the maximum value, and points of measurements, be specified.

17.3.5.8 Electrostatic shielding. In certain applications, it is necessary to reduce stray pickup of rf noise and similar undesirable signals from the contacts of a reed relay. This can be accomplished by a nonmagnetic metallic shield which surrounds the switch capsule and is fastened to an appropriate grounding pin or terminal. Normally this shield is placed between the reed switch and the coil. On multiple contact relays, it is also common to have each of the individual switch elements shielded and in turn have all of these shields shielded from the coil and have this shield grounded. The shield will prevent the noise generated by the arcing of the reed switch contacts from affecting other elements closely adjacent to the relay in the circuit.

17.3.5.9 Contact protection. The opening of relay contacts in an inductive load normally produces a high transient voltage. For example, it is not unusual for a 24-Vdc circuit to produce transients in excess of 1,000 V. Certain other loads, such as motor loads and lamp loads, will have inrush currents upon contact closure considerably higher than the steady state value. Inrush currents of 10 times steady state currents are common in lamp loads.

**17.4 RELAYS, TIME-DELAY
AND SENSOR**

17.4 Time-delay and sensor.

17.4.1 Introduction. There are several basic methods of controlling delay time with respect to a switching function. The common time-delay relays or timing devices are thermal, pneumatic, hydraulic, motor-driven, and electronic. Each of the devices mentioned has certain advantages and should be studied for suitability to each application.

The type of action performed by a time delay-relay can be generalized by two basic actions. In the time-delay on "make," the time-delay occurs starting at the instant the power is turned on and actuates contacts some specific time later. In this case, power is available for use in the electronic circuitry during the time-delay period.

For the time-delay on "break," turning the power on activates a set of contacts. The removal of power initiates the time delay, after which the contacts return to their normal position. In this case, the external power may not be available during the timing period. Thus, the energy required for activating the time-delay circuit must either be stored within the device during the power "on" period, or must be obtained from an auxiliary power source to which the time-delay is connected at all times.

Combinations of more than one time-delay circuit of either or both of the types may be made to produce special timing devices, either with sequential action or with self-regenerating timing cycles.

The most commonly used time delay is the time delay on "make," either used singly or in combination circuits to provide sequential timing systems.

Sensor relays are available which sense voltage levels, under or over voltage condition, frequency of an ac voltage, phase sequence, or a combination of these conditions. It may incorporate time delay on "make" or "break."

These devices are not included in MIL-STD-975.

17.4.1.1 Applicable military specifications.

MIL-R-28894	Relay, Hybrid or Solid State, Sensor, Established Reliability
MIL-R-83726	Relay, Hybrid and Solid State, Time Delay

17.4.2 Usual applications. The unique features of the sensor and time-delay relays have caused them to be widely accepted for many types of circuit switching. The specific application should determine the style and type of the time delay relay best suited for the particular design requirement. The following operating characteristics and design information can be helpful in determining the various parameters to meet specific design applications.

17.4 RELAYS, TIME-DELAY AND SENSOR

17.4.2.1 Description of time delay relay functions. The following figures illustrate several time-delay relay functions. Figure 11 shows time delay on operate condition. Figure 12 is time delay on release for units with separate control and power inputs, and Figure 13 is time delay on release for common control and power input. Figure 14 shows an interval timer. Figure 15 shows a repeat cycle timer.

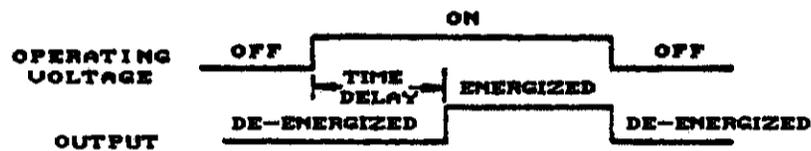


FIGURE 11. Time delay on operate.

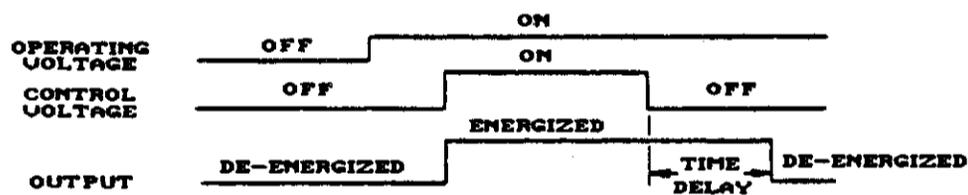


FIGURE 12. Separate control and power inputs.

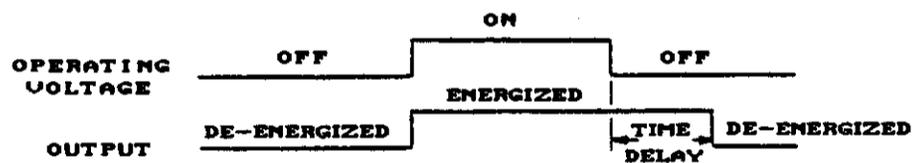
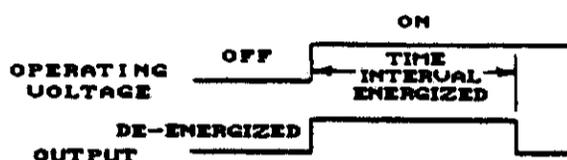
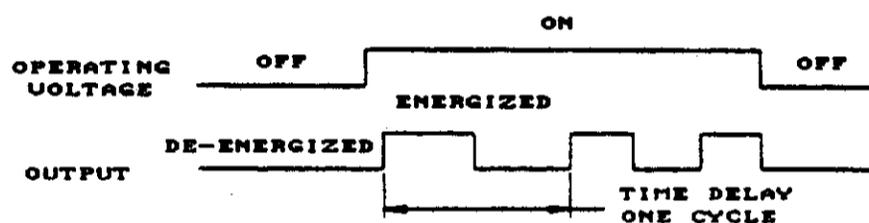


FIGURE 13. Common control and power input.

FIGURE 14. Interval time.FIGURE 15. Repeat cycle timer.

17.4.3 Physical construction and mechanical characteristics. The information pertaining to electromechanical output for armature relays in paragraph 17.2.3 is applicable to time-delay and sensor relays. Additional characteristics will be addressed in the following paragraphs.

17.4.3.1 Solid state (hybrid) time-delay relay. The most popular circuit used in solid state time-delay relay utilizes the RC, resistance and capacitance, charge principle and a programmable unijunction transistor. When a voltage is applied to the input the capacitor charges at a rate controlled by the RC network. At a voltage level controlled by the programmable unijunction transistor, the capacitor discharges through the relay coil and causes the relay to operate. A special input circuit is used which provides transient protection well over 1,000 V. The input is also protected against reverse polarity.

17.4.3.2 Copper slug time delay. The delay time is produced by placing a copper slug around the relay core. This produces a counter magnetomotive force (mmf) which produces the desired time delay on operate or release.

17.4 RELAYS, TIME-DELAY AND SENSOR

A time-delay can be produced on a dc relay by placing one or more shorted turns around the magnetic circuit, usually the core, to produce a counter mmf. This retards the buildup of the operating flux, and upon de-energization, provides mmf to retard the collapse of the flux. This shorted turn, or turns, is called a slug. Usually it consists of a copper collar on the core of the relay. In order to produce an effective delay, it is necessary to use a slug of considerable cross section, often equal to or larger than that of the coil itself. Although this method of time delay is applicable on any dc relay with sufficient space to accommodate this slug, it is most commonly used on telephone type relays and relays which have comparatively long coils and can easily accommodate this slug. A copper slug positioned at the armature end of the coil core retards magnetic build-up and provides long operate-delay with short-delay in release time. A copper slug positioned at the heel end of the coil core provides a long release time-delay with short delay in operate time.

The principle of operation of the slug is as follows: When the relay coil is energized, the flux build-up passes through the slug and by self-inductance produces an mmf that opposes the coil mmf. This opposing mmf delays the build-up of the magnetic field in the air gap to a strength that will cause the armature to close. The time delay on drop-out occurs in the opposite manner. When the coil is de-energized, the field starts to collapse, inducing a current in the slug. This in turn provides an mmf orientated to sustain the magnetic field and delay the drop-out. There are many factors that affect the time delay produced by slug relays. For this reason, each application must take into consideration coil power, armature gap, residual gap, amount of residual force required to move and close contacts, etc. to obtain required delay time.

17.4.3.3 Solid state-static output time delay relay. In this type of time-delay relay a solid state circuit performs the timing function, and an SCR or triac semiconductor performs the output switching. When voltage is applied to the input terminals, the timing delay is initiated. At the end of the electronically controlled period, a completely isolated solid state switch is energized. The switch leads are connected in series with the load and the supply voltage and are capable of handling ac current or dc current of either polarity. The device may switch the same voltage as applied to the control input or it may switch current to an isolated load from a secondary ac or dc current to a load from a dc power supply. Polarity need not be observed through the load switch; however, both the ac input voltage and the dc load current must be momentarily interrupted to reset the timer.

The solid state design of this time delay relay enables it to be used in specialized control applications where explosion-proof switching or operation in a corrosive atmosphere with arcless and bounceless time control is required.

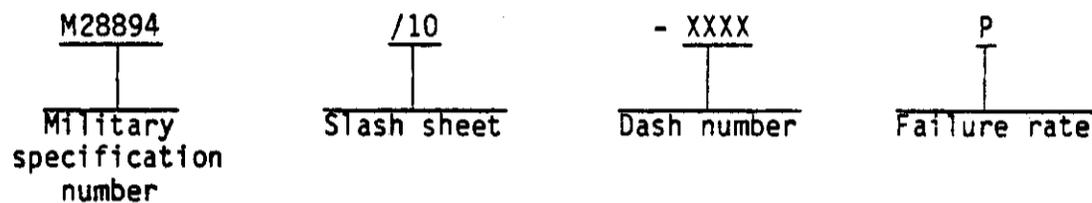
17.4.3.4 Sensor relays. Hybrid and solid state sensors are available with an under and over voltage, phase sensing, or frequency detection capability. In addition to these combinations, some sensors also incorporate a time delay on operate or release. The sensors are available with contact ratings ranging from low level to 10 A.

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17.4.3.4.1 AC sensors. The sensors are capable of detecting an under voltage or over voltage condition, monitoring frequency, proper phase sequence, open neutral lines, or a combination of these features. Sensing accuracy is based on a true sinusoidal input waveform. Output status is provided by an electro-mechanic relay or solid-state logic.

17.4.3.4.2 DC sensors. Sensors are capable of detecting a specified dc voltage level and providing a status output when the prescribed requirements are met.

17.4.4 Military designation. MIL-R-28894 and MIL-R-83726 are the general military specifications for sensor and time-delay relays. The proper method of specifying the part number is:



17.4.5 Electrical characteristics. The basic considerations are covered in paragraph 17.1.4. The output characteristics of the time-delay and sensor relays are common to all electromechanical relays, and the ratings, configuration, and requirements are given in the referenced paragraph.

17.4.5.1 Reset. The reset time indicated for the various standard time delay relays is based on a typical time delay relay tested at the nominal voltage at room temperature. This number should not be construed as a maximum or minimum condition, but a typical value of reset time in milliseconds of a typical time delay relay.

17.4.5.2 Time-delay mode. The primary function of a time delay relay is to perform a given timing function, while satisfying the electrical and mechanical requirements of the application. The most popular timing modes are slow operate or slow release. However, time-delay relays are available in other timing modes, such as interval, totalizer, nontotalizer and momentary actuation. Functions are described in paragraph 17.4.2.

17.4.5.3 Time-delay tolerance. When choosing a time-delay relay, a major application consideration may be the repeatability tolerance of the relay. The standard repeatability tolerances are ± 1 percent, ± 5 percent and ± 10 percent. Other tolerances can be made available on special order. Recognition should be given to the fact that, in general, the broader the tolerance the lower the cost.

17.4.6 Environmental considerations. The typical environmental conditions are included in the referenced military specifications.

17.4.7 Reliability considerations. Paragraph 17.1.6 is concerned with general reliability data for relays and should be consulted for reliability considerations and failure mode data pertinent to time-delay relays.

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AND SENSORS**

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18.1 WIRE AND CABLE, GENERAL

18. WIRE AND CABLE

18.1 General.

18.1.1 Introduction. This section contains general information on electrical wire and cable listed in MIL-STD-975 NASA Standard Electrical, Electronic, and Electromechanical (EEE) Parts List. It is intended to help the designer select a wire or cable for a specific application. The referenced military specifications and MIL-STD-975 should be consulted.

In the following sections, specification requirements are discussed to assist the designer in narrowing the selection to a few choices. The most important decision is which of the numerous wire insulations, conductor configurations, and terminating hardware will be the most suitable for use in specific applications. Proper selection is the first step in building reliable equipment. To make the best wire and cable selection, the user must know as much as possible about the different wire types available. The designer should be aware of the advantages and disadvantages, the behavior of wire under various environmental conditions, the construction, the problems of termination, and the effects of chemical compounds that come into contact with the wire and its insulation. The designer should also be aware of the system requirements for temperature extremes, voltage/current requirements, and design constraints that could adversely affect wire and cable performance.

18.1.1.1 Applicable specifications.

MIL-W-22759	Wire, Electric, Fluoropolymer-Insulated, Copper or Copper Alloy
MIL-W-81381	Wire, Electric, Polyimide-Insulated, Copper or Copper Alloy
MIL-W-5086	Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy
MIL-W-16878	Wire, Electrical, Insulated, General Specification for
MIL-C-17	Cables, Radio Frequency, Flexible and Semirigid, General Specification for
MIL-C-27500	Cable, Electrical, Shielded and Unshielded, Aerospace

18.1.2 Definitions. The following terms in this section are to define words that might not be familiar to the designer. However, the intent is not to serve as a complete reference book of terms. If further information is needed, refer to the applicable military specification or consult an electrical engineering handbook.

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Abrasion resistance. Ability to resist surface wear.

Aging. The change in properties of a material with time under specific conditions.

American wire gauge (AWG). The standard system used for designating wire diameter. Formerly referred to as the Brown and Sharpe (B&S) wire gauge. For solid wire, this gauge is characterized by a doubling in wire diameter for a six-step reduction in AWG number. Stranded wire, because of geometrical considerations of the strandings, is usually not equal in cross-section to a solid wire, but is designated by the closest AWG number.

Anneal. To heat and then gradually cool in order to relieve mechanical stresses.

Blocking. The property (usually considered undesirable) of the insulation of wire wound in closely spaced turns adhering to each other at elevated temperatures. All military specifications for wire require that a blocking test be performed to show that this does not occur at the specified temperature.

Bond strength. The amount of adhesion between bonded surfaces.

Bonding. The adhesion of insulation material to a conductor.

Breakdown (puncture). A disruptive electrical discharge through insulation.

Breakdown voltage. The voltage at which the insulation between two conductors will break down.

Cable. Two or more insulated conductors, solid or stranded contained in a common covering (sheath, shield, or jacket); two or more insulated conductors twisted or molded together without common covering; one or more insulated conductors with a metallic covering shield or outer conductor (insulated or uninsulated).

Characteristic impedance. A characteristic of coaxial cable which is a function of the two diameters of the conductors and the dielectric constant of the insulation material. Although called an impedance, it is actually a resistance that is independent of frequency and represents the ac resistance at rf frequencies of an infinitely long cable. Values of nominal characteristic impedance used in space programs are standardized at 50 ohms, 75 ohms, and 95 ohms.

Coaxial cable. A cable configuration consisting of a conductor in a cylindrical geometry with the center conductor insulated from the concentric outer conductor, with these dimensions accurately controlled. In general, these cables are designed for low loss, stable operation from relatively low frequencies to the high frequencies encountered in the microwave region of the frequency spectrum. Cables may also be used as circuit elements such as delay lines and for impedance matching devices. Coaxial cables are normally classified by their characteristic impedance.

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Cold flow. The property (usually undesirable) of a solid insulation material (such as TFE), to flow or slowly displace away from a highly localized stress region caused by a point, corner, or even tight lacing. In severe cases, cold flow of the insulation will expose the wire conductor causing contact with the stress-producing object.

Conductivity. Reciprocal of volume resistivity. Conductance of a unit cube of a 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.

Conformal coating. A process of coating which generally follows the contours of the assembly, providing resistance to mechanical shock and environmental conditions.

Continuous lengths. Wire is normally manufactured in a continuous process. If, during the spark test, for example, an insulation failure is detected, that section of wire is cut out, leaving a gap in the reel. Military specifications require documentation listing the lengths of wire in the order in which they will be unspooled, so that installation personnel will be certain that the wire they are working with will be long enough for the immediate application.

Copper alloy, high strength. In applications where weight saving is critical and increased conductor resistance is not a factor, high strength copper alloy conductors are recommended. AWG 26 high strength copper alloy has approximately the same breaking strength as AWG 24 copper with two thirds the weight. The increase in resistance is approximately 4.5 times.

Copper conductor. Most electrical wire consists of a copper conductor of high purity and in an annealed condition which permits easy bending, and offers low electrical resistance. In wire sizes 24 AWG and smaller, the softness and small size cause the copper conductors to become increasingly more fragile with normal handling.

Corona. A luminous discharge due to ionization of the gas surrounding a conductor around which exists a voltage gradient exceeding a certain critical value.

Corona resistance. The time that insulation will withstand a specified level field-intensified ionization that does not result in immediate complete breakdown of the insulation.

Critical pressure region. High altitude region where the dielectric strength of air becomes less than 20 percent of the sea level dielectric strength of 70 volts/mil. This is approximately 65,000 ft (50 torr) to 310,000 ft (5×10^{-4} torr). Above this altitude, into "hard" vacuum, the dielectric strength rapidly increases. The minimum, at which the dielectric strength of air becomes essentially zero, is approximately 110,000 ft. This is also called the "Paschen" minimum. Because of the many uncontrolled factors involved, these limits are emphasized as being "approximate."

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Cut-through. Resistance of solid material to penetration by an object under conditions of pressure, temperature, etc.

Delamination. The separation of layers in a laminate through failure of the adhesive.

Dielectric. Any insulation material between two conductors. This material is characterized by a high ohmic resistance in comparison to the conductor resistance.

Dielectric constant. The ratio of the capacitance of a capacitor with the given dielectric to the capacitance of a capacitor having air for its dielectric but otherwise identical. Also called permittivity, or specific inductive capacity.

Dielectric strength. The maximum voltage which an insulating material can withstand before breakdown occurs. See Voltage Gradient.

Dissipation factor. The tangent of the loss angle of the insulating material.

Elongation. Stretching characteristic of ductile flexible or elastomeric materials while under tension. If the yield point is exceeded (which is very low for annealed copper wire), the wire will not return to its original length when the load is removed. All military specifications define elongation rather than breaking stress as a requirement for annealed copper wire.

Embedment. A process by which circuit components are encased in a dielectric material, usually poured in as a liquid, then hardened. This includes both potting and encapsulation.

Encapsulation. An embedment process in which the resin is cast in removable molds.

ETFE. Common trade name "Tefzel".

FEP. Common trade name "Teflon".

Flammability test. A measure of the ability of insulation material to support combustion under specified test conditions.

Fluoropolymer. Plastic materials having fluorine and other elements, usually carbon. Some examples are polytetrafluoroethylene (PTFE), fluorinated ethylene propylene (FEP), and modified ethylene tetrafluoroethylene (ETFE) used as wire insulation materials in MIL-W-22759. Although the designation for the first is properly called out as "PTFE," to minimize confusion throughout this document, the shorter acronym "TFE" will be used to correspond with existing military specifications. These materials are characterized by toughness and flexibility at low temperatures (even down to absolute zero), lower dielectric constants than any other solid materials, and operation for years near their melting temperature of 327 °C without significant change in properties. TFE in the presence

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of oxygen has a rather low radiation resistance under high energy radiation (10^7 - 10^8 rads dose) becoming embrittled, and disintegrates, emitting gaseous products. Trade name "Teflon" for TFE.

Ground support equipment (GSE). Equipment not intended for flight, and designed for ground installation to support flight projects.

Harness. One or more insulated wires or cables, with or without helical twist; with or without common covering, jacket or braid; with or without breakouts; assembled with two or more electrical termination devices and so arranged that as a unit, can be assembled and handled as one assembly.

Impedance. The total opposition that a circuit offers to the flow of alternating current or any other varying current at a particular frequency. It is a combination of resistance R and reactance X measured in ohms and designated by Z.

Impulse. A voltage or current surge of unidirectional polarity.

Impulse dielectric test. A method of checking insulation integrity of wire or shielding by passing the wire through a bead chain on which high negative impulses are continuously applied. The wire or shielding is grounded during the test, and a circuit is used to detect voltage breakdown.

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. A measure of the insulation integrity or quality of the material in contact with conductors.

Insulation system. All of the insulation materials used to insulate a particular electrical or electronic product.

Jacket. An insulating material applied over the primary insulation of wire (MIL-W-5086) or over shielding (MIL-C-27500) for protective purposes.

Lay. The axial distance required for one conductor strand to be wound helically around a central strand.

Lay, concentric. A central strand surrounded by one or more layers of helically wound strands. It is optional for the direction of lay of the successive layers to be alternately reversed (true concentric lay) or in the same direction (unidirectional lay).

Lay, length of. Defined in MIL-W-81381 as not less than 8 nor more than 16 times the maximum conductor diameter as specified.

PFA. Perfluoroalkoxytetrafluoroethylene, material used for jacketing of cables.

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Polyimide. Polyimides are a family of high-temperature resistant thermoset and thermoplastic resins. Polyimide insulations are applied to wire listed in MIL-STD-975 tape form, 0.1 mil FEP, 1.0 mil polyimide, and 0.1 FEP, wound with 50 percent minimum overlap, then sintered or heated to fuse the layer together. Trade name "Kapton."

Potting. An embedment process in which the container (can) used in the embedment remains as part of the completed assembly.

Primary insulation. Insulation applied to conductors which determines the wire voltage rating. Other insulation materials, such as jackets, are not included.

Red plague. A deterioration problem encountered early in the space program through the use of silver-coated copper wire; however, controlled wire manufacturing processes will reduce the incidence of this problem. Red plague results from a combination of several factors. In wire manufacture, the insulation material is usually applied by a hot extrusion process over the wire in a continuous operation. Originally, this extruded wire was cooled by passing it through a water bath. In the cooling process, an occasional pin hole in the insulation sucked in the water during the cooling of the internal gases. Even though this pin hole would be later detected by suitable high voltage sparking techniques and the subsequent section of wire cut out, the water which had entered through the hole would travel a great distance up and down the wire strand. In the case of a silver coating on the wire, the coating is not continuous but is porous, exposing the copper underneath. The presence of moisture forms a battery by galvanic action producing cuprous oxide corrosion red in color and thus designated "red plague." Tin-coated and nickel-coated copper wire do not exhibit this reaction because they are much closer to copper than is silver in the galvanic series. Replacing the water quench with an air blast or other dry cooling during the wire insulating manufacturing process normally eliminates this problem. Also, silver-coated copper wire must be manufactured in a low-humidity environment.

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; of surface resistivity, the ohm.

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 and presence of surface contamination.

Surge. A transient variation in the current or voltage at a point in the circuit.

Tensile strength. The breaking stress of a material under tension, usually expressed in psi. For purposes of comparison with high strength copper alloy, which is 52,000 psi, annealed copper is assumed to be 36,000 psi.

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TFE. Common trade name "Teflon". See Fluoropolymer.

Thermoplastic. A classification of resin that can be readily softened and resoftened by repeated heating.

Thermosetting. A classification of resin which cures by chemical reaction when heated and, when cured, cannot be resoftened by heating.

Time delay. 1. The time required for a signal to travel between two points in a circuit. 2. The time required for a wave to travel between two points in space.

Velocity of propagation. The ratio of the speed of the flow of an electric wave in a coaxial cable to the speed of light, expressed as a percentage. The speed of the electric wave is governed solely by the properties of the dielectric medium and the permeability of the conductor through which it is transmitted. In free space, electromagnetic energy travels at the speed of light, 3×10^8 meters per second which is by definition 100 percent. In a coaxial cable with a uniform dielectric of a relative permeability greater than 1, the VP is less than 100 percent, in the same ratio.

The equation is $VP\% = \frac{100}{\sqrt{\epsilon}}$, where ϵ dielectric constant of the insulation.

For solid, extruded PTFE, $\epsilon = 2.07$

An equivalent equation is $VP\% = \frac{101670}{Z_0 C}$, where Z_0 = characteristic impedance
 C = capacitance in pf/ft.

Voltage gradient. A measure of the maximum stress placed on an insulating material between two conductors, usually expressed in volts/mil. For parallel plates the voltage gradient in volts/mil is the voltage applied to the plates divided by the separation in mils. For other geometries such as parallel or crossed cylinders (wires) or cylinder to plane, etc, the curved surfaces magnify the gradients over the parallel plate calculation, and different equations are required to determine the gradients.

Voltage standing wave ratio (VSWR). The ratio of the voltage maximum to the voltage minimum of the standing waves occurring in an r-f or coaxial cable not terminated in its characteristic impedance when connected to an r-f source.

Volume resistivity (specific insulation resistance). The electrical resistance between opposite faces of a 1-cm cube of insulating material, commonly expressed in ohm-centimeters. The recommended test is ASTM D 257-61.

Wicking. 1. Upward flow of solder underneath the insulation during soldering of stranded wire, stiffening it. 2. Flow of moisture or other contaminant underneath the insulation of wire.

Wire. A single metallic conductor of solid, stranded, or tinsel construction, designed to carry current in an electrical circuit. It may be bare or insulated, but does not have a metallic covering, sheath, or shield.

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18.1.3 General wire characteristics. The wire and cable section of MIL-STD-975 lists control specifications for standard wire and standard cable. These control specifications, with their specified slash sheets, give a wide range of characteristics and parameters for selection for a given application.

In addition to providing electrical continuity adequate for the functioning of the circuitry and interconnection of subsystems and maintaining adequate insulation between the various conductors to prevent shorting, many other factors must be considered which influence the selection of wire. Some of these factors are:

- a. Limitations on weight, size, and cost
- b. Rated voltage of the wire
- c. Ease of stripping, termination, and replacement
- d. Flexibility and bondability
- e. Environmental considerations
- f. Space versus ground support applications
- g. Resistance to solder and to damage from soldering irons
- h. Resistance to solvents
- i. Resistance to cut through, cold flow, and abrasion.

A first consideration in wire application is that the wire should be used within its design limitations and in the class of service for which it is intended. Because multiconductor cables, other than coaxial, are made up of individual wires, the limitations of the wire type should be considered. Special design considerations for electrical requirements are as follows:

- a. The current, voltage, and frequency requirements
- b. The number and type of conductors
- c. Shielded, rf, coaxial
- d. Type and physical characteristics
- e. Noise generation and emi considerations.

Depending on whether the application is for space or ground support, the following special environmental parameters are considered:

- a. The outgassing characteristics of the insulation material
- b. The expected temperature rise characteristics

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- c. Vacuum exposure effects
- d. Expected launch pad environments.

All of the considerations and constraints are discussed in separate paragraphs for guidance of the designer in comparing the various parameters of available wires.

18.1.4 Materials.

18.1.4.1 Conductor materials and plating. With the exception of the solid center conductors in the coaxial cables listed in MIL-STD-975 all of the wire conductors are stranded. Stranded is preferred over solid wire because it is easier to bend and is considered more reliable in vibration environments. The number of strands used in the conductor is limited to those which will give a perfect lay with all the strands the same diameter.

The conventional conductor material for electrical wire has been soft, annealed copper, as pure as possible, to achieve the lowest resistance. In applications where the weight is an overriding factor with resistance secondary, a high strength copper alloy is available. As an example, AWG 26 copper alloy has approximately the same breaking strength as pure AWG 24 copper but only two thirds the weight due to the smaller diameter. Also, the number of flexures that pure copper wire can withstand without work hardening or breaking is severely limited, compared to copper alloy, especially in the smaller sizes (26 to 32).

Because of the ductility of annealed copper, the military specifications have no tensile strength requirements. Rather, the minimum elongation is defined as that distance the wire is stretched before breakage of the first strand occurs. Elongation is also specified for copper alloy wire, and in addition, a tensile breaking stress is given. To enable comparison by designers, tensile strengths of the various AWG wire sizes are calculated by the product of the copper cross-sectional area and 36,000 psi, the accepted breaking strength of pure copper.

All copper and copper alloy wire conductors used in MIL-STD-975 are required to be plated or coated to inhibit corrosion of the conductor. Three plating materials are called out, each having a specific application which is a function of temperature and method of termination: tin, silver and nickel. Tin, the most common and least expensive coating used in electronic wiring, has an upper temperature limitation of 150 °C. Although intended for solder termination, tinned copper wire can also be used for crimping.

Silver- and nickel-coated wires have upper temperature limits of 200 °C and 260 °C, respectively. Silver-coated wire permits terminating both by soldering and crimping. However, silver coated wire is susceptible to cuprous oxide corrosion (red plague) when produced, stored, or used in a moist or high-humidity environment. Therefore, the environment must be controlled. The higher temperature ratings for silver- and nickel-coated wire ordinarily approach that of the insulation material itself, which is approximately 260 °C.

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Of the three materials, nickel is able to withstand corrosion much better than the other two and still maintain a good electrical connection. Because of the difficulty of soldering nickel, this wire is intended mainly for crimp-type terminations. Nickel wire can be soldered, provided that high temperature soldering equipment and active fluxes are used. Highly corrosive fluxes should be avoided.

Table I presents typical values for weight tensile strength, and resistance at common wire sizes.

TABLE I. Parameters for standard wires

Wire Size	Stranding (Number of Strands x AWG size of Strand)	Weight, Max ^{2/} lbs/1000 feet		Tensile Strength lbs ^{2/}			Resistance, Nominal Ohms/1000 feet ^{2/}		
		Bare Solid Copper Wire	Finished Wire	Copper		Copper Alloy	Solid Copper Wire	Nickel Plated Copper ^{1/}	Nickel Plated Alloy ^{1/}
				Solid	Stranded	Stranded			
30	7 x 38	0.303	1.00	3.1	3.2	5.17	104	114	129
28	7 x 36	0.481	1.36	5.0	4.9	8.16	65.3	68.6	79.0
26	19 x 38	0.765	1.90	7.9	8.6	14.2	41.0	41.3	49.4
24	19 x 36	1.22	2.58	12.7	13.4	22.4	25.7	26.2	30.1
22	19 x 34	1.94	3.68	19	21	36	16.2	16.0	18.6
20	19 x 32	3.10	5.36	32	34	58	10.1	9.77	11.4
18	19 x 30	4.92	7.89	49	54		6.39	6.10	
16	19 x 29	7.81	9.95	78	69		4.02	4.76	
14	19 x 27	12.4	14.9	124	109		2.52	3.00	
12	37 x 28	19.8	22.6	197	172		1.59	1.98	
10	37 x 26	31.4	35.1	314	265		1.00	1.24	
8	133 x 29	50.0	63.5	480	480		0.628	0.694	
6	133 x 27	79.4	99.9	763	759		0.395	0.436	
4	133 x 25	126	157	1213	1206		0.249	0.275	
2	665 x 30	201	245	1929	1882		0.156	0.177	
1	817 x 30	253	324	2423	2310		0.124	0.144	
0	1045 x 30	319	391	2984	2960		0.098	0.133	
00	1330 x 30	402	504	3763	3760		0.078	0.089	

^{1/} Silver and tin plated wires are not shown in this table.

^{2/} These parameters are typical. Consult the appropriate specifications for specific values.

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18.1.4.2 Insulation materials.

18.1.4.2.1 Types. Various types of insulation are used in the wire and coaxial cable callouts for MIL-STD-975. These include:

- a. Extruded tetrafluoroethylene. This insulation is applied over the conductor by means of a continuous extrusion process.
- b. Polyimide. Three layers of insulation fabricated over the conductor. The first layer is a fluorocarbon/polyimide composite tape consisting of 0.1 mil of fluorinated ethylene propylene (FEP) fluorocarbon resin, then 1 mil of polyimide film (trade name "Kapton") followed by another layer of 0.1 mil FEP. This is wound with a 50 percent (min) overlap over the conductor. The second layer is an identical film wound in a "cross lay" or opposite direction over the first layer. Finally, a modified aromatic polyimide resin coating 0.5 mil (min) is applied over the previously wound tapes. They are fused by a sintering process to become an integral insulation.
- c. An insulation system using polyvinyl chloride (PVC) as a primary insulation. In MIL-W-5086 wire, an additional nylon jacket is extruded over the PVC. This jacket serves to protect the PVC insulation from mechanical damage and adds a "slipperiness" to allow this wire to be pulled through conduits and other applications without the insulation binding. MIL-W-16878 wire has the PVC insulation without the jacket. Both of these PVC insulated wires are for GSE use only.
- d. Coaxial cable insulations are Type F-1 extruded polytetrafluoroethylene (PTFE, or by earlier designation TFE), which are preferred for the higher frequencies and configurations indicated in the specific slash sheets.

18.1.4.2.2 Color. The color designation codes for individual wire permitted by MIL-STD-975 are listed in Table II, which is taken from MIL-STD-681. Additional information can also be found in the referenced military specification.

18.1.4.2.3 Flammability. Wires with polyvinyl chloride insulation shall not be used in aerospace applications. Application in space transportation system (STS) payloads may require that the specific STS flammability hazards be addressed. Users are advised to consult the appropriate project systems safety officer.

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TABLE II. Color sequence for single wires

Base Color	Stripe or Band	Color Designation No.
Black		0
Brown		1
Red		2
Orange		3
Yellow		4
Green		5
Blue		6
Violet		7
Gray		8
White		9
White	Black	90
White	Brown	91
White	Red	92
White	Orange	93
White	Yellow	94
White	Green	95
White	Blue	96
White	Violet	97
White	Gray	98

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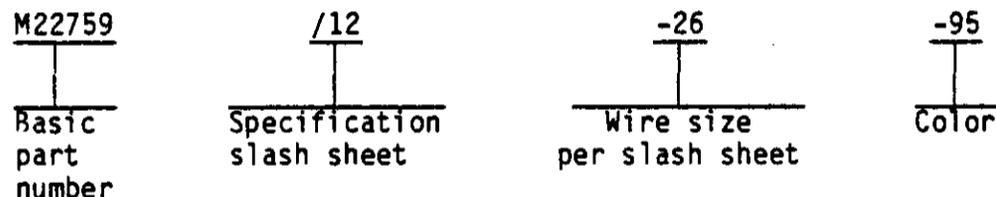
18.2 WIRE AND CABLE, FLUOROPOLYMER-INSULATED, MIL-W-22759

18.2 Wire, fluoropolymer-insulated, MIL-W-22759.

18.2.1 Introduction. This specification covers fluoropolymer-insulated single conductor electric wires made with tin-coated, silver-coated, or nickel-coated conductors of copper or copper alloy ranging from AWG 28 to AWG 00, depending on the particular slash sheet. The fluoropolymer insulation of these wires may be polytetrafluoroethylene (TFE) or ethylene-tetrafluoroethylene copolymer (ETFE).

18.2.2 Usual applications. Wires fabricated to this basic specification and applicable slash sheets may be used in ground support, aircraft, and space applications in accordance with their performance characteristics. Specifically, this includes cable harnesses and interconnection (hookup) wire for chassis and electronic subsystems for long-term high-reliability applications. Note that for space applications, the outgassing properties of wire fabricated to this specification are not controlled and must be evaluated for compliance with program requirements. Because of TFE cold-flow characteristics, care must be exercised in the design to assure that cable lacings or wire routing will not cut or bring pressure to bear on the insulation.

18.2.3 Part number designation. The complete part number designation is as follows.



As an example, an M22759/12 wire, 260 AWG size, white with green stripe would have a complete number, M22759/12-26-95.

18.2.4 Physical construction.

18.2.4.1 Conductor configuration. The conductors of wire sizes 28 through 10 AWG consist of a central strand surrounded by one or more concentric layers of helically wound strands as shown in Figure 1. Conductors of sizes 8 through 00 AWG are in a rope lay configuration concentrically wound with a central member surrounded by one or more layers of helically wound members as shown in Figure 2.

18.2.4.2 Conductor materials. Two conductor materials are available, pure copper and high-strength copper alloy. The pure copper conductors are used for larger sizes of wire and for applications where the wire resistance is an important consideration. The advantage of high-strength copper alloy is that it allows a smaller diameter with the same breaking strength for applications where weight is critical and where the increase in conductor resistance

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**18.2 WIRE AND CABLE, FLUOROPOLYMER-
INSULATED, MIL-W-22759**

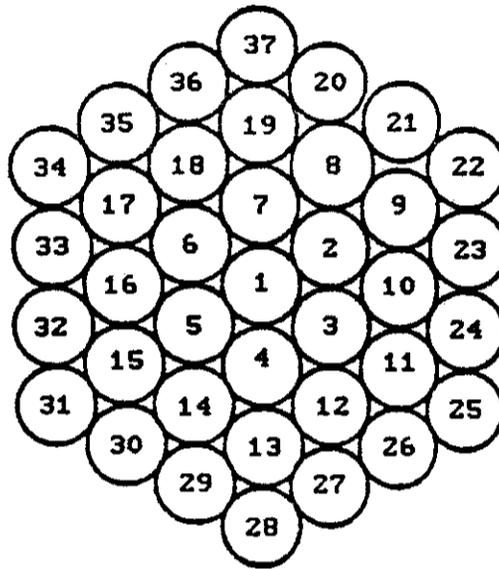


FIGURE 1. Stranded wire configuration for 7, 19, and 37 strands, for respective sizes 28 through 10.

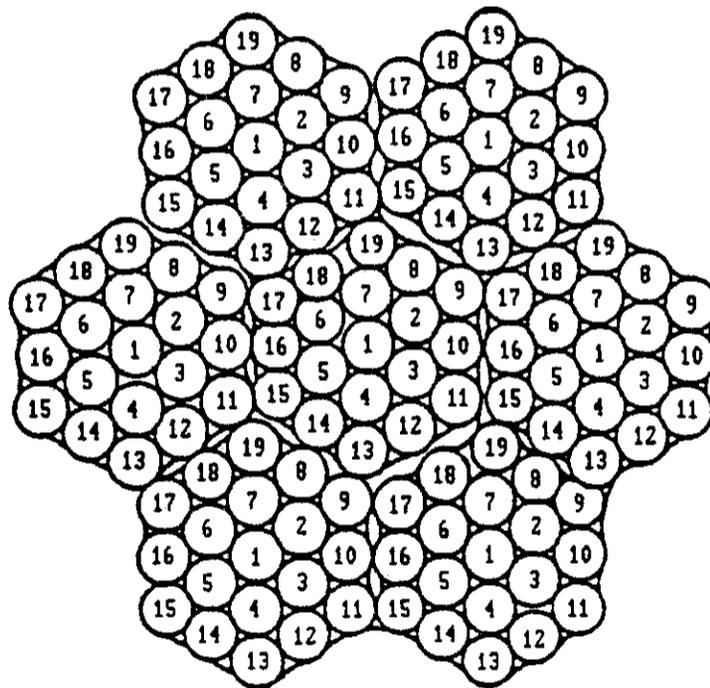


FIGURE 2. Typical rope-lay configuration, wire sizes 8 through 4 (sizes 2 through 0000 use additional bundles).

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**18.2 WIRE AND CABLE, FLUOROPOLYMER-
INSULATED, MIL-W-22759**

is not significant to the operation of the electronic equipment. Specific applications are signal cable harnesses. As an example, size 26 AWG high-strength copper alloy wire has approximately the same breaking strength as size 24 AWG pure copper wire. The "breaking strength" of pure copper is not given in military specifications because of its extreme ductility and the difficulty of determining when a break occurs. To assist the designer in selection, Table IV compares the tensile strengths of solid copper, stranded copper, and high-strength copper alloy of the same size. These values are calculated from the cross-sectional areas, assuming a pure copper ultimate tensile strength of 36,000 psi and copper alloy of 55,000 psi.

18.2.4.3 Conductor coatings/platings. Three conductor coatings are available in the specification slash sheets listed. Nickel-coated wire is intended mainly for crimp type termination because of the difficulty in soldering nickel. Nickel-coated wire can only be soldered when high temperature equipment and active fluxes are used. Silver-coated or tin-coated wire can be terminated by either crimping or soldering.

Active fluxes are not recommended for use. Corrosive fluxes should be avoided.

18.2.4.4 Insulation configurations. With the exception of M22759/3, the insulation materials of TFE or ETFE are applied over the conductor by an extrusion process. As shown in Figure 3, the first layer against the conductor consists of either TFE-skived tapes or TFE-coated glass tapes, or a combination of both, spirally wrapped on the conductor. The intermediate coat consists of TFE-coated glass braid and TFE finisher followed by a TFE tape jacket consisting of two layers cross-lapped. The layers are fused or sintered to eliminate the possibility of the jackets unwrapping. Extruded TFE over the conductor is more common and should have fewer voids than wound layers. Elimination of voids becomes important in applications such as high voltage to prevent corona.

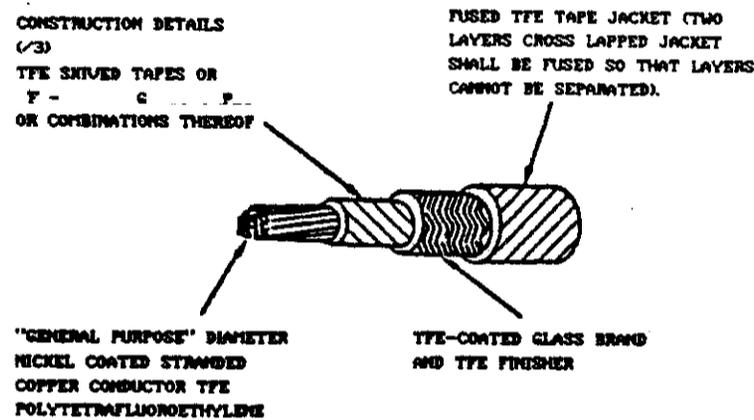
18.2.5 Electrical characteristics.

18.2.5.1 Conductor resistance. The electrical resistance of wire is specified as ohms per 1,000 feet measured at 20 °C. Resistance values for uncoated solid copper wire and coated stranded wire are compared in Table I. The resistance value as given is essentially that of pure copper, since the coating has a minor effect on the overall resistance. Silver-coated wire has slightly lower resistance than the tin-coated or nickel-coated wires. Specifications M22759/22 and /23 have silver-coated high-strength copper alloy and nickel-coated high-strength copper alloy conductors, respectively, and include only five wire sizes, from 28 to 20 AWG.

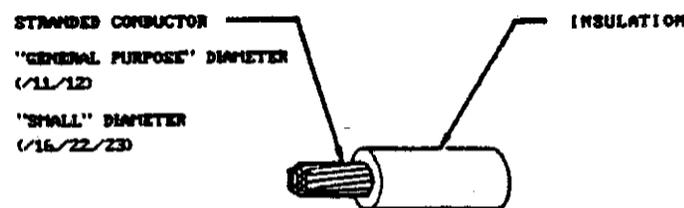
18.2.5.2 Working voltage. Although the working voltage of all the wires in this section is 600 V rms at sea level at the highest temperature rating of the insulation, it is customary to apply derating factors to all maximum ratings as a safety factor in high reliability applications (refer to Appendix A of MIL-STD-975). Even though the wire is rated at 600 V, it is required to pass an impulse dielectric test of from 6.5 to 8 KV at room temperature.

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18.2 WIRE AND CABLE, FLUOROPOLYMER-INSULATED, MIL-W-22759



A. TFE-glass-TFE



B. Extruded TFE

FIGURE 3. Typical construction, MIL-W-22759 wire.

18.2.5.3 Insulation resistance. The insulation resistance is a measure of the insulation integrity of the wire conductor coating. Depending on the wire specification, the range of insulation resistance values for 1,000 ft is from 5,000 MΩ to 50,000 MΩ minimum. Usually, the insulation resistance is not of significance in electronic circuits unless the wire is very long and is used in very high impedance applications where the insulation shunting effect might affect the signal voltage. The insulation resistance goes up as the lengths become shorter.

18.2.5.4 Current rating. The current ratings of wires are not usually considered unless significant current is involved which will cause heating of the wire due to the I^2R loss. Such a temperature rise must be added to the maximum environmental temperature to determine the actual temperature of the wire and, in any case, must not exceed the temperature rating of the wire itself. Currents flowing in wires in a bundle have a cumulative heating effect that must be taken into account. Refer to derating in Appendix A of MIL-STD-975.

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**18.2 WIRE AND CABLE, FLUOROPOLYMER-
INSULATED, MIL-W-22759**

18.2.6 Environmental considerations. In selecting a wire for specific applications, all the environments which the wire will encounter must be taken into consideration. For example, humidity is not a problem for a spacecraft in space, but might be at a launch center if the space vehicle were there for any length of time.

The outgassing properties of these wires are not controlled and must be evaluated for compliance to project outgassing requirements.

Silver-coated wire is susceptible to cuprous oxide corrosion (red plague) when stored or used in a moist or high-humidity environment.

18.2.7 Reliability considerations.

18.2.7.1 TFE, ETFE, and FEP insulating material. Since the conductor configurations are essentially the same for all military specification wires, considerations of reliability will be applied to the insulation materials. These insulation materials are chemically inert and have reasonable dielectric strength, resistance to high temperature, and flexibility at low temperatures. The chemical inertness property of these materials introduces a problem in applications where bonding to encapsulation materials is required such as encapsulation of the wiring ends of connectors. To achieve a reliable bond, an etchant material must be used. Another problem with TFE and FEP is cold flow under pressure or cut-through strength of the material. A bundle of TFE- or FEP-insulated wires held together with a very tight lacing (cord) could be cut through the insulation material down to the conductors. A similar problem is created where the wire passes over a corner or edge. Excessive stress applied to the wire may cause the corner to gradually penetrate the insulation all the way to the conductor.

18.2.7.2 Voltage. All of the wires in this section have a voltage rating of 600 Vrms at the maximum operating temperature at sea level. The intent of this rating is to establish a reference point for which this wire insulation is capable of withstanding indefinitely with the outer surface of the insulation at ground potential or zero voltage.

Other waveforms or higher frequencies may result in a reduction of the voltage rating. If the wires are encapsulated or otherwise separated from the ground plane, then the stress on the wire insulation itself is reduced with the same voltage applied. This rating does not apply to wire operating in the critical pressure region where corona discharge may take place from the surface of the wire to the ground plane. To prevent corona, the voltage rating should be 190 Vrms at 60 Hz, which gives a peak voltage of 270 V, the limiting value for breakdown in air at any pressure. If operation of the wire in the critical air pressure region at higher ac voltages up to 600 Vrms is desired, then additional steps are required to eliminate corona or dielectric breakdown.

MIL-HDBK-978-B (NASA)

**18.2 WIRE AND CABLE, FLUOROPOLYMER-
INSULATED, MIL-W-22759**

Because of the effects of all these conditions, it is mandatory for the designer to apply derating factors to all maximum ratings in high reliability applications to take into account unanticipated problems. The derating factors are presented in Appendix A of MIL-STD-975.

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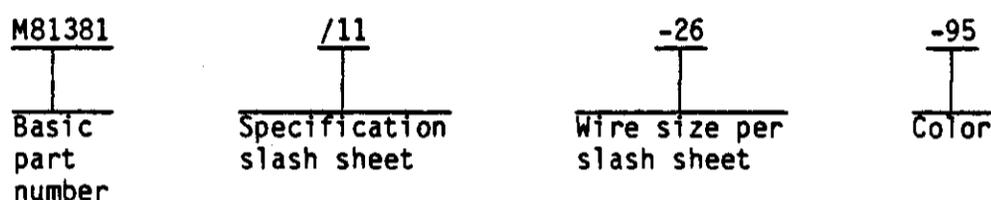
18.3 WIRE AND CABLE, FLUOROCARBON/
POLYIMIDE-INSULATED, MIL-W-81381

18.3 Wire, fluorocarbon/polyimide-insulated, MIL-W-81381.

18.3.1 Introduction. This specification covers light weight fluorocarbon/polyimide-insulated single-conductor electric wires made with tin-coated, silver-coated, or nickel-coated conductors of copper or high-strength copper alloy. The wire sizes range from 30 to 10 AWG depending on the slash sheet.

18.3.2 Usual applications. Wires fabricated to the basic specification and applicable slash sheets may be used in ground support, aircraft, and space applications in accordance with their performance characteristics. Specifically, this includes cable harnesses and interconnection (hookup) wire for chassis and electronic subsystems for long-term high-reliability applications. Note that for space applications, the outgassing properties of wire fabricated to this specification are not controlled and must be evaluated for compliance with program outgassing requirements. Generally, this wire should not come into contact with liquid missile propellants.

18.3.3 Part number designation. The complete part number designation is as follows.



As an example, an M81381/11 wire, 26 AWG size, white with green stripe would have a complete number of M81381/11-26-95.

18.3.4 Physical construction.

18.3.4.1 Conductor configuration. The conductors of sizes 30 through 10 AWG consist of a central strand surrounded by one or more concentric layers of helically wound strands, as shown in Figure 4.

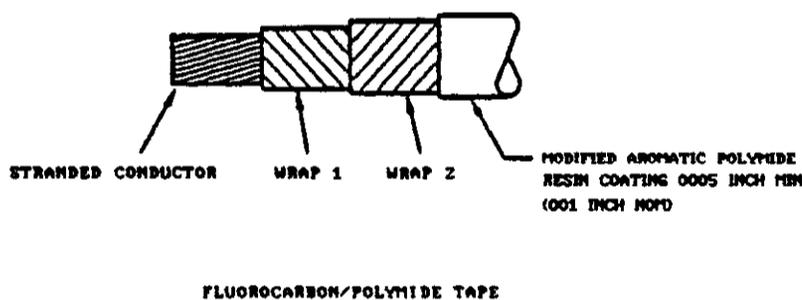


FIGURE 4. Typical construction, MIL-W-81381 wire.

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**18.3 WIRE AND CABLE, FLUOROCARBON/
POLYIMIDE-INSULATED, MIL-W-81381**

18.3.4.2 Conductor materials. Two conductor materials are available, pure copper and high-strength copper alloy. Pure copper conductors are used for larger sizes of wire and for applications where the wire resistance is an unimportant consideration. The advantage of high-strength copper alloy is that it allows a smaller diameter with the same breaking strength for applications where weight is critical and the increase in conductor resistance is not significant to the operation of the electronic equipment. Specific applications are signal cable harnesses. As an example, size 26 AWG high-strength alloy copper wire has approximately the same breaking strength as size 24 AWG pure copper wire. The breaking strength of pure copper is not given in military specifications because of its extreme ductility and the difficulty of determining when a break occurs. To assist the designer in selection, Table I compares the tensile strengths of solid copper, stranded copper, and high-strength copper alloy of the same size. These values are calculated from the cross-sectional areas, assuming a pure copper ultimate breaking strength of 36,000 psi and copper alloy of 55,000 psi.

18.3.4.3 Conductor coatings/platings. Three conductor coatings are available in the specification slash sheets listed. A selection of the coating material is dependent on the method of termination and maximum temperature to which the wire will be exposed. Of the wires listed in this specification, nickel- and silver-coated wire have the highest temperature rating of 200 °C. Because of the difficulty of soldering nickel, nickel-coated wire is intended mainly for crimp-type terminations.

18.3.4.4 Insulation configuration. The fluorocarbon/polyimide insulation is in the form of a tape which is spirally wound with a 50-percent minimum overlap around the conductor. A second tape of the same configuration is wound over the first with an opposite lay. Each tape is specified by a tape code as .1/1/.1, which means 0.1 mil FEP fluorocarbon resin/1 mil polyimide film /0.1 mil FEP fluorocarbon resin. "FEP" is fluorinated ethylene propylene. A sintering process fuses the tapes together to form a continuous coating.

18.3.5 Electrical characteristics.

18.3.5.1 Conductor resistance. The electrical resistance of wire is specified as ohms per 1,000 ft measured at 20 °C. Resistance values for uncoated solid copper and coated stranded wire are compared in Table I. The resistance value as given is essentially that of the pure copper, since the coating has a minor effect on the overall resistance. Silver-coated wire has slightly less resistance than the tin- or nickel-coated wires.

18.3.5.2 Working voltage. Although the working voltage of all the wires in this section is 600 V rms at sea level at the highest temperature rating of the insulation, it is customary to apply derating factors to all maximum ratings as a safety factor in high reliability applications. Even though the wire is rated at 600 V, it is required to pass an impulse dielectric test of 8 KV at room temperature. See Appendix A of MIL-STD-975.

MIL-HDBK-978-B (NASA)

**18.3 WIRE AND CABLE, FLUOROCARBON/
POLYIMIDE-INSULATED, MIL-W-81381**

18.3.5.3 Insulation resistance. The insulation resistance is a measure of the insulation integrity of the wire conductor coating. The insulation resistance is 2500 M Ω minimum. Usually, the insulation resistance is not of significance in electronic circuits unless the wire is very long and is used in very high impedance applications where the insulation resistance shunting effect might affect the signal voltage. The insulation resistance goes up as the length becomes shorter.

18.3.5.4 Current rating. The current ratings of wires are not usually considered unless appreciable current is involved which will cause heating of the wire due to the I^2R loss. Such temperature rises must be added to the maximum environmental temperature to determine the actual temperature of the wire and must not exceed the temperature rating of the wire itself. Currents flowing in wires in a bundle have a cumulative heating effect that must be taken into account. See derating of wires in Appendix A of MIL-STD-975.

18.3.6 Environmental considerations. In the selection of the wire for a specific application, all the environments which the wire will encounter must be taken into consideration. For example, humidity is not a problem for a spacecraft in space, but might be at a launch center if the space vehicle were there for any length of time.

The outgassing properties of these wires are not controlled and must be evaluated for compliance to project outgassing requirements.

Silver-coated wire is susceptible to cuprous oxide corrosion (red plague) when stored or used in a moist or high-humidity environment.

18.3.7 Reliability considerations.

18.3.7.1 Polyimide insulating material. Because the conductor configurations are essentially the same for all military specification wires, considerations of reliability will be applied to the insulation materials. Polyimide insulating materials are difficult to strip and are less flexible than TFE and FEP. The hygroscopic nature of polyimide insulation should be considered when used for high-humidity or moist environments. Liquid oxygen compatibility is inferior to that of TFE and FEP.

18.3.7.2 Voltage. All of the wires in this section have a voltage rating of 600 Vrms at the maximum operating temperature at sea level. The intent of this rating is to establish a reference point for which the wire insulation is capable of withstanding indefinitely with the outer surface of the insulation at ground potential or zero voltage. Different waveforms or higher frequencies may result in a reduction of the voltage rating. If the wires are encapsulated or otherwise separated from the ground plane, then the stress on the wire insulation itself is reduced with the same voltage applied. This rating does not apply to wire operating in the critical pressure region where corona discharge may take place from the surface of the wire to the ground plane. To prevent corona, the voltage rating should be 190 Vrms at 60 Hz, which gives a peak voltage of 270 V, the limiting value for breakdown in air at any pressure.

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**18.3 WIRE AND CABLE, FLUOROCARBON/
POLYIMIDE-INSULATED, MIL-W-81381**

If operation of the wire in the critical air pressure region at higher ac voltages up to 600 Vrms is desired, then additional steps are required to eliminate corona or dielectric breakdown.

Because of the effects of all these conditions, it is mandatory for the designer to apply derating factors to all maximum ratings in high-reliability applications to take into account unanticipated problems. The derating factors are presented in Appendix A of MIL-STD-975.

MIL-HDBK-978-B (NASA)

**18.4 WIRE AND CABLE, POLYVINYLCHLORIDE
(PVC) INSULATED COPPER, MIL-W-5086**

18.4 Wire, polyvinylchloride (PVC) insulated copper, MIL-W-5086.

18.4.1 Introduction. This specification covers PVC-insulated, single-conductor electric wire made with tin-coated copper conductors listed as "general purpose" diameters in the applicable military specification sheets. For M5086/1 and M5086/2, the wires called out in MIL-STD-975 employ PVC insulation in combination with other insulating and protective materials. MIL-W-5086 prohibits the usage for aerospace application.

18.4.2 Usual applications. NASA has restricted M5086/1 and M5086/2 wire to GSE applications. This wire can be used for internal wiring for electric and electronic equipment. The nylon jacket, which protects the primary insulation, has a slipperiness that facilitates its being pulled through conduits for cable harnesses. The wire sizes called out in MIL-STD-975 are the larger sizes which are intended for power and current applications rather than low-level signal wiring.

18.4.3 Part number designation. The complete part number designation is shown below.



As an example, an M5086/2 wire, 16 AWG size white with green stripe would have a complete part number of M5086/2-0016-95.

18.4.4 Physical construction.

18.4.4.1 Conductor materials. Although the MIL-W-5086 general specification calls out both copper and copper alloy conductors, /1 and /2 which are designated in MIL-STD-975 are for copper only. Figure 5 presents the typical configuration for this wire.

The "breaking strength" of pure copper is not given in military specifications because of its extreme ductility and the difficulty of determining when a break occurs. To assist the designer and enable comparison with wire listed in other sections, Table I lists the breaking strengths based on an assumed copper ultimate strength of 36,000 psi and 55,000 psi for copper alloy.

18.4.4.2 Insulation configuration. The insulation for the M5086/1 wire sizes 16 through 12 AWG has two layers consisting of an extruded polyvinyl chloride primary insulation over the conductor followed by a jacket of extruded nylon.

The M5086/2 insulation has three layers. The first is the same as M5086/1, the second is glass fiber braid with finisher. For size 10, the third layer is an extruded jacket of clean nylon which is the same as that in M5086/1. For the larger sizes, 8 through 0000, a nylon braid jacket with nylon finisher is used.

MIL-HDBK-978-B (NASA)

18.4 WIRE AND CABLE, POLYVINYLCHLORIDE
(PVC) INSULATED COPPER, MIL-W-5086

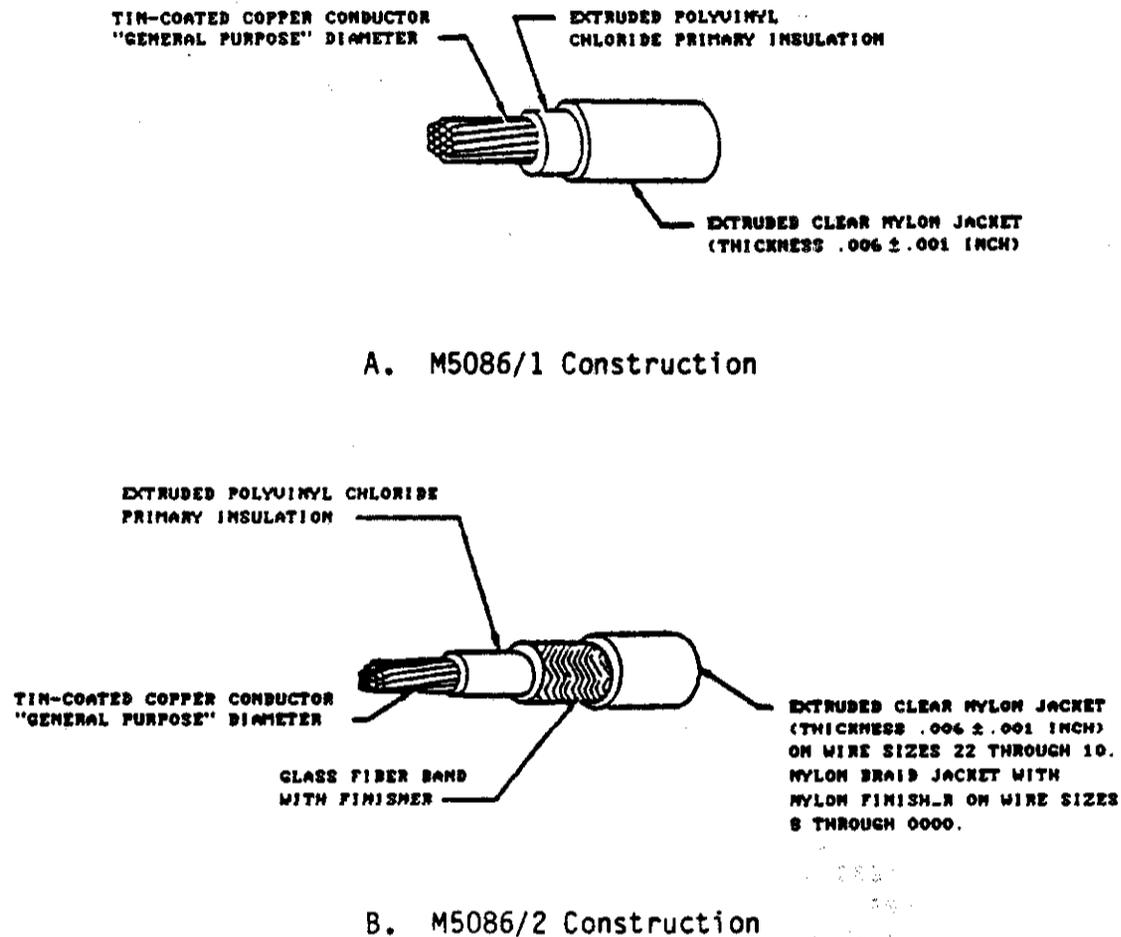


FIGURE 5. Typical construction, MIL-W-5086.

18.4.5 Electrical characteristics.

18.4.5.1 Conductor resistance. Table I identifies the resistance in ohms per 1,000 feet at 20 °C for each size of stranded conductor listed. For comparison, the resistance per 1000 ft for solid wire is also given. The AWG sizes are exact only for the solid wire. Cross-sectional areas for stranded wire may vary as much as 20 percent of the nominal for solid wire.

18.4.5.2 Working and test voltages. The working voltage of all wires in this section is specified as 600 V ac rms at sea level at the highest temperature rating of the insulation. However, it is customary to apply derating factors to all maximum ratings as a safety factor in high reliability application. Refer to Appendix A of MIL-STD-975.

MIL-HDBK-978-B (NASA)

**18.4 WIRE AND CABLE, POLYVINYLCHLORIDE
(PVC) INSULATED COPPER, MIL-W-5086**

Since the insulation is applied in two steps, an intermediate spark or impulse dielectric test is required to prove the integrity of the extruded primary insulation before the nylon jacket is extruded over it. The specifications require that 100 percent of the wire must be tested, both the primary and completed insulation.

18.4.5.3 Insulation resistance. The insulation resistance is a measure of the insulation integrity at the wire conductor coating. The insulation resistance for M5086/1 wire is specified at 500 M Ω for 1,000 ft minimum, and for M5086/2 wire the insulation resistance for size 10 is specified at 40 M Ω for 1,000 ft. No requirements are given for sizes 8 through 0000 AWG.

18.4.5.4 Current rating. The sizes of copper conductors called out in MIL-STD-975 show that these wires are intended for high-current applications such as long runs, heavy power distribution for launch complexes, or similar installations. Since these applications require runs consisting of many cables together, the cumulative heating effects of the cable I²R losses must be taken into account. See derating of wires in Appendix A of MIL-STD-975.

18.4.6 Environmental considerations. The temperature rating of 105 °C represents the maximum permissible operating temperature of the conductor. The maximum allowable ambient temperature should be no more than 105 °C minus the operating rise in temperature of the conductor due to I²R loss.

18.4.7 Reliability considerations. Since the conductor configurations are essentially the same for all MIL-W-5086 wires, considerations of reliability will be applied to the insulation materials. The PVC insulation materials are characterized by reasonable dielectric strength, ease of stripping, flexibility at low temperatures, bondability to most encapsulation materials, and low cost. The problem of low abrasive resistance is overcome in MIL-W-5086 wire by the extruded nylon jacket. Since these wires are not approved for space applications, low outgassing and stability in a vacuum are not prerequisites. Resistance to cold flow and cut-through is very good. The wire is easy to strip and handle, which facilitates manufacturing operations.

CAUTION

PVC materials emit harmful fumes when overheated and should not be applied in confined areas in which there is inadequate ventilation or where crew and test personnel can ingest harmful gases.

MIL-HDBK-978-B (NASA)

**18.5 WIRE AND CABLE, WIRE, POLYVINYLCHLORIDE
(PVC INSULATED, MIL-W-16878)**

18.5 Wire, polyvinylchloride (PVC) insulated, MIL-W-16878.

18.5.1 Introduction. This specification covers polyvinylchloride (PVC) insulated wires made with tin-coated stranded copper conductors from sizes 32 to 18 AWG, rated for 600 V and limited by MIL-STD-975 to ground support equipment use only. MIL-STD-975 makes available to the designer a range of wire sizes from 32 to 0000 AWG with essentially the same characteristics. Each size in MIL-W-16878/1 calls out several stranding configurations. The stranding configurations authorized for use by MIL-STD-975 are 7 strands for sizes 32 through 28 AWG and 19 strands for sizes 26 through 18 AWG.

18.5.2 Usual applications. This wire is authorized by MIL-STD-975 only for ground support equipment. This is unshielded wire for internal hookup and lead wiring for electrical and electronic equipment and switchboards.

18.5.3 Part number designation. The part number designation for ordering or a drawing callout is as follows.

M16878	/1	-B	-C	-B	-96
Basic part number	Specification slash sheet (/1 only)	Conductor material (B = copper only)	Conductor size (A = 32 to H = 18)	Number of strands (B = 7, E = 19)	Base color (white with blue stripe)

As an example, a seven stranded copper wire, 18 AWG size, white with green stripe would have a complete part number of M16878/1-B-H-B-95.

18.5.4 Physical construction.

18.5.4.1 Conductor configuration. Specification MIL-W-16878/1 calls out either solid or stranding configuration, different conductor materials, and tin or silver coating for each wire size. MIL-STD-975 selects the stranded copper, tin-coated wire.

These conductors from sizes 32 to 18 AWG are the conventional configuration consisting of a central strand surrounded by one or more layers of helically wound strands. The strands are positioned in a geometric arrangement of concentric layers to produce a smooth and uniform conductor, circular in cross-section, free of any crossovers, high strands, or other irregularities. The number of strands of each helically wound layer are selected so as to completely fill the available space. The stranding is shown in Figure 6.

The conductor sizes and corresponding size designations are in accordance with established usage for stranded copper conductors for hookup wire in the electronic and aircraft industries. The cross-sectional areas of the stranded conductors in most sizes only roughly approximate those of solid conductors of the same numerical AWG designation.

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**18.5 WIRE AND CABLE, WIRE, POLYVINYLCHLORIDE
(PVC INSULATED, MIL-W-16878)**

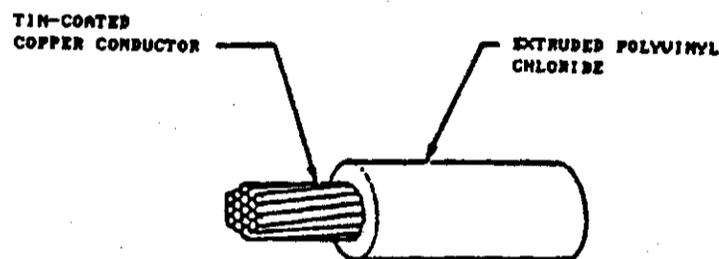


FIGURE 6. Typical construction, MIL-W-16878.

18.5.4.2 Conductor material. Annealed pure copper is the only material called out as the conductor material. Practical experience has shown that copper wire smaller than size 24 is fragile and difficult to handle; consequently its use is not recommended for high reliability applications. Because the "breaking strength" of pure copper conductors is not given in military specifications, calculated values based on an assumed ultimate strength for copper of 36,000 psi are listed in Table I. The designer can make comparisons with the copper alloy wire of the same AWG sizes also listed in Table I.

18.5.4.3 Conductor coating. Only a tin coating is specified.

18.5.4.4 Insulation configuration. The insulation for this wire consists of a single layer of polyvinyl chloride extruded over the conductor.

18.5.5 Electrical characteristics.

18.5.5.1 Conductor resistance. Table I shows the resistance in ohms per 1000 ft at 20 °C for stranded wire and for comparison, solid wire of the same AWG. AWG sizes are exact only for the solid wire. The cross-sectional area for stranded wire is from 5 to 17 percent larger than the equivalent solid-wire areas over this range. Since the cross-sectional area of the stranded wire is greater than that for the equivalent AWG solid wire, a lower resistance would be expected for the stranded; this is not the case for the six sizes, 32 through 22, shown in Table I. Note that the resistance for the solid wire is nominal, whereas that for stranded is a maximum that is set for wire vendors as a "not-to-exceed" specification. Also, the solid wire is uncoated and the stranded is coated, affecting resistance differently. In short, no simple relationship exists between the stranded and solid-wire resistances.

18.5.5.2 Working voltages. The maximum recommended working voltage at sea level and at the maximum temperature is specified as 600 Vac rms between conductor and ground for continuous operation. For dc voltages, this value may be 40 percent higher. However, it is customary to apply derating factors to all maximum ratings as a safety factor in high reliability applications. Refer to Appendix A of MIL-STD-975.

**18.5 WIRE AND CABLE, WIRE, POLYVINYLCHLORIDE
(PVC INSULATED, MIL-W-16878)**

18.5.5.3 Insulation resistance. The insulation resistance is a measure of the insulation integrity of the wire conductor coating, in this case polyvinyl chloride (PVC). An equation is given in M16878/1 to calculate the insulation resistance for each AWG wire size as a function of the insulation volume between the conductor and the outer insulation surface.

18.5.5.4 Current ratings. The current ratings of wires are not considered significant unless significant power is involved. Significant current passing through the wire will cause heating of the wire due to the I^2R loss. Such a temperature rise must be added to the maximum environmental temperature to determine the actual temperature of the wire and in any case must not exceed the temperature rating of the wire itself. Currents flowing in wires in a bundle have a cumulative heating effect that must be taken into account. Refer to derating of wire in Appendix A of MIL-STD-975.

18.5.6 Environmental considerations. The temperature rating of 105 °C represents the maximum permissible operating temperature of the conductor. The maximum allowable ambient temperature should be no more than 105 °C minus the operating rise in temperature of the conductor due to I^2R loss.

18.5.7 Reliability considerations. Since the conductor configurations are essentially the same for all wires called out in MIL-STD-975, considerations of reliability will be applied to the insulation materials. Polyvinyl chloride (PVC) has an operating temperature range of -54 to +105 °C maximum and is characterized by good abrasion resistance, flexibility, high strength, excellent electrical properties (including low water absorption), high cut-through strength, easy strippability, and low cost. The PVC materials have been used extensively in electrical and electronic wiring applications. The material is easily bondable with various encapsulation and potting compounds in applications such as potted connectors.

For such applications as pulling multiple wires through a conduit, wire types with a nylon jacket over the PVC are recommended. This is because the "slipperiness" of the nylon permits easier pulling and protects the PVC insulation from mechanical damage.

The PVC wire shows good tolerance to nuclear and high-energy-particle radiation. However, as previously stated, PVC-insulated wire is recommended by MIL-STD-975 only for ground support applications because of toxic smoke when burned.

This wire is intended for use as a single conductor in the internal wiring of electrical and electronic equipment and switchboards. The general specification points out that wire sizes having a thin-wall insulation of 0.007-in. thickness or less, intended for limited, low-voltage applications, are relatively fragile and easily damaged, and should not be used where chemical stresses or abrasive environments may exist. Precautions should be taken using MIL-W-16878/1 wire, since the lower limits of the finished wire diameter, in comparison with the sizes of the conductors, result in a wall thickness of 0.007 in.

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**18.5 WIRE AND CABLE, WIRE, POLYVINYLCHLORIDE
(PVC INSULATED, MIL-W-16878)**

MIL-W-16878/1 further states that this wire may not be suitable in circuits requiring the highest degree of reliability. Care must be taken in installation to avoid damaging the dielectric with a hot soldering iron and to leave no residual physical strain on the dielectric wall because plastic flow may result in failures.

The conductor sizes on the corresponding size designations of MIL-W-16878/1 are in accordance with established usage for stranded-copper conductors or hook-up wire in the electronic and aircraft industries, although these wire-size designations are not identical with AWG sizes for solid wire. The diameters and cross-sectional areas of the stranded conductors of this specification are, in most sizes, only roughly approximate to those of AWG solid conductors in the same numerical size designation.

**.6 WIRE AND CABLE, CABLE, RADIO-
FREQUENCY, FLEXIBLE, COAXIAL, MIL-C-17**

18.6 Cable, radio-frequency, flexible, coaxial, MIL-C-17.

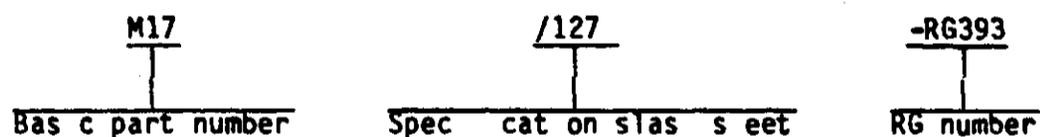
18.6.1 Introduction. This section covers cables with a coaxial configuration, consisting of a center conductor, concentric insulation material and an outside braided conductor. Coaxial cables are distinguished from single-conductor shielded wire by the requirement that the ratio of the outside diameter of the center conductor and inside diameter of the outer conductor must be maintained accurately to achieve optimum transmission line characteristics at radio frequencies. Maintenance of these dimensions also achieves a constant series inductance per foot and parallel capacitance per foot, which are characteristics of rf cable configurations.

Neglecting other factors for the moment, the selection of a coaxial cable over a single-wire shielded configuration is dictated when the wavelength of the highest-frequency signal being transmitted over the wire becomes significant with respect to the length of the cable. Quantitatively, this is usually when the length of cable is 5 to 10 percent of the wavelength of the highest frequency involved. Another factor which may dictate the selection of a coaxial cable is the availability of coaxial connectors. Coaxial cables can also be used as pulse forming lines and as capacitive or inductive impedance elements at high frequencies although cables are usually specifically designed for such applications.

Coaxial cables designated in MIL-STD-975 are of the flexible type, most commonly used in aerospace systems. These cables are characterized by a woven mesh outer conductor, in contrast to rigid and semirigid coaxial cables which have a solid aluminum or copper outer conductor that usually can be bent to a given configuration, although they are not considered flexible.

18.6.2 Usual applications. Coaxial cables are primarily intended for applications requiring the transfer of rf energy from one location to another. The rf can consist of a single frequency as in continuous wave (CW) or pulse wave forms requiring a wide band capability.

18.6.3 Part number designation. The part number designation is as follows:



18.6.4 Physical construction. The center conductor of the coaxial cables is either a single-strand steel wire, copper-covered and silver-coated, or a stranded copper conductor. Because of the small diameters involved, the steel wire is required for strength, whereas the copper covering is a base for the silver coating which is used to improve the conductivity of the center conductor at rf frequencies.

18.6 WIRE AND CABLE, CABLE, RADIO-FREQUENCY, FLEXIBLE, COAXIAL, MIL-C-17

The dielectric core is solid extruded TFE of the precise outside diameter to obtain the design nominal characteristic impedance. The outer conductor consists of one or two layers of a woven braid of silver-coated round copper wire. The braid coverage is usually specified as a percentage, approximately 90 percent (approximately 10 percent of the area is taken up by small holes and gaps in the weave of the braid). In some low-level applications where emi is a consideration, the percentage coverage becomes important. Double-braid helps to give a more complete coverage to the outer conductor. Typical construction shown in Figure 7.

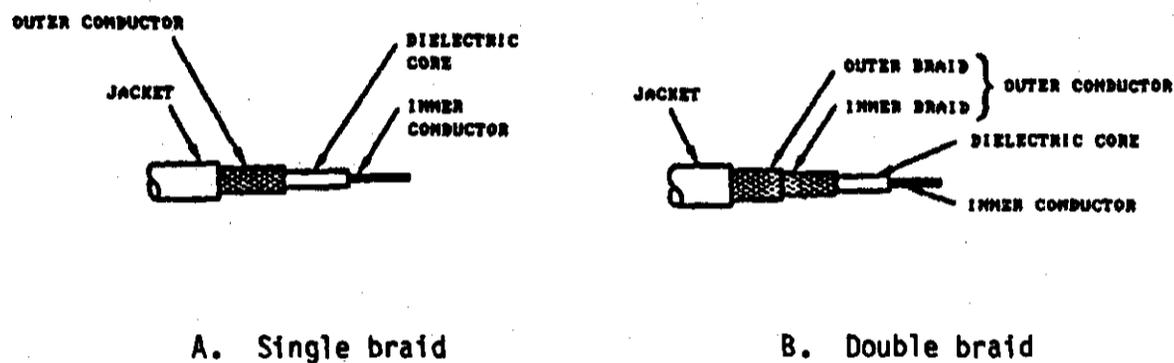


FIGURE 7. Typical construction, MIL-C-17 cable.

All cables have the outer conductor covered by an FEP jacket to protect the braid from damage in handling and to keep out moisture.

Eccentricity. Analysis shows that the eccentricity limit of MIL-C-17, which permits the center conductor to be displaced 10 percent of the OD from the center, reduces the characteristic impedance by 1 percent. The limits on the various characteristic impedances are given in ohms, \pm from the nominal value, which figures to be ± 4 percent. The eccentricity factor is among other various manufacturing tolerances, such as variations in dielectric constant, etc, which, added together, will be within the 4 percent allowed. If the design application requires closer tolerance for the characteristic impedance, then an investigation should be made to select the proper cable.

Conductor adhesion. The maximum and minimum adhesion requirements for the center conductor allow for handling and stripping. The minimum is set high enough to permit handling and flexing of the coaxial cable without separation of the dielectric from the center conductor, thus preventing the occurrence of voids which would generate electrical noise in low-level circuits and corona in high-voltage applications. The high limit is set to facilitate stripping without exerting an undue amount of force which might damage the cable.

18.6 WIRE AND CABLE, CABLE, RADIO-FREQUENCY, FLEXIBLE, COAXIAL, MIL-C-17

Elongation and breaking loads. Elongation minimums in percent and the ultimate tensile strength minimum in lbs per square inch are specified in the slash sheets, but the basic specification cites an ASTM specification rather than addressing the procedures to measure these parameters.

18.6.5 Electrical characteristics.

18.6.5.1 Characteristic impedance. For a coaxial configuration, the characteristic impedance of a cable is given by $Z_0 = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{D}{d}$, where D is the ID of the outside conductor, d is the OD of the inner conductor, and ϵ is the dielectric constant of the insulation material. This quantity Z_0 is the effective impedance (resistance) that would be encountered by an ac circuit connected to a coaxial cable infinitely long.

If the cable is cut and a resistor equal to the characteristic impedance is connected across the end, the effect on the sending end is unchanged. Impedances which have been selected as standard are 50 ohm, 75 ohm, and 95 ohm.

If the cable termination is either open circuited or short-circuited, this discontinuity causes a reflection in the applied signal as it propagates to the end. This reflection causes voltage standing waves and is expressed as a voltage standing wave ratio (VSWR) in power applications. A high VSWR in power systems dissipates power in the cable, causing localized heating and increased losses. For low level and signal pulse circuits, the termination in other than the characteristic impedance causes reflections of the pulses. It is a good practice to terminate a coaxial cable in its characteristic impedance to prevent these effects.

18.6.5.2 Maximum operating frequencies. Coaxial cables operate in the transverse electromagnetic (TEM) mode. The TEM mode has both the electric and the magnetic fields normal to the direction of propagation. The possibility of propagation in the higher modes limits the usefulness of the coaxial cable to below the lowest mode cutoff frequency. The maximum operating frequency given in the specification is derated sufficiently from the TEM cutoff frequency to prevent any possibility of operation of the cable in higher modes. Other factors contributing to a lower operating frequency are the elements of the construction of the cable and associated connectors. The recommended operating frequency takes into account all of these factors, but designers should always check the capabilities of cables, connectors, and assemblies before operating at any high frequency near cutoff.

18.6.5.3 Attenuation. The reduction or attenuation of the signal passing through the cable as a function of frequency is plotted in each slash sheet except /94 and /95, where single values are listed. Note that the attenuation is given in db per 100 ft, and increases with frequency. The db attenuation at cable lengths other than 100 ft can be calculated by the direct length ratio. Also note that the attenuation is for the cable only. Attenuation values for connectors must be added to the cable to obtain the overall maximum attenuation.

18.6 WIRE AND CABLE, CABLE, RADIO-FREQUENCY, FLEXIBLE, COAXIAL, MIL-C-17

18.6.5.4 Power ratings. The power rating is a maximum power handling capability, in watts, that a coaxial cable can safely transmit without overheating or developing dielectric breakdown throughout the useful frequency range. This maximum power as a function of frequency is plotted in each slash sheet.

Because of the increased dielectric loss as the frequency is increased, the power transferring capability of the cable goes down. In order to keep the cable from exceeding its maximum allowable temperature, in MIL-C-17 these power ratings assume a VSWR of 2 and an ambient temperature from 38 °C to +149 °C for TFE dielectric, and also a maximum inner conductor temperature of +200 °C for TFE.

18.6.5.5 Capacitance. The capacitance of a coaxial cable is determined by the ratio of the inner and outer conductor diameters and the dielectric constant of the insulation material. This quantity is usually specified in picofarads per foot. For low frequencies or dc applications, the total capacitance of an open circuit cable is the capacitance per foot times the number of feet. At higher rf frequencies the reactance of the series inductance becomes significant. The length of the cable becomes an appreciable fraction of the wavelength of the applied rf signal and the input impedance becomes capacitive or inductive, depending on the length of the cable and the frequency applied.

18.6.5.6 Maximum continuous working voltage. The maximum continuous working voltage is the ac rms voltage that can be continuously applied to the coaxial cable. This voltage is limited by the onset of corona discharge or partial breakdown. In MIL-C-17, this working voltage is 75 percent of the corona extinction voltage for sea-level atmospheric conditions and 60 Hz test voltages. Higher frequencies and operation at high altitudes will reduce the corona inception voltages. For high voltage applications, tests and evaluation of these parameters should be made before the design is finalized.

18.6.5.7 Insulation resistance. Because of the high performance requirements of the dielectric materials for high frequency applications, insulation resistance is not considered applicable to coaxial cables.

18.6.5.8 Current ratings. The current ratings of the designated coaxial cables are considered adequate for space applications so that overloading of the center conductor is not a problem. No requirement for current is stated in the basic MIL-C-17 specification or in the slash sheets. However, the I^2R loss for a high current application should be evaluated since a maximum resistance for the center conductor is designated for each of the coaxial cables. This value is intended as a check on the method or adequacy of termination to assure that there is a good joint between the connector and the cable.

18.6.6 Environmental considerations. Outgassing properties of these cables are not controlled and must be evaluated for compliance to project outgassing requirements.

18.6 WIRE AND CABLE, CABLE, RADIO-FREQUENCY, FLEXIBLE, COAXIAL, MIL-C-17

Silver-coated copper conductors, whether used as shielding or as a center conductor, are susceptible to cuprous oxide corrosion (red plaque) when stored or used in moist or high-humidity environments.

18.6.7 Reliability considerations. Good practice sets a minimum bend of 6 times the jacket diameter of the coaxial cable but 10 times is more desirable. Care should be taken in the forming and handling of any flexible coaxial cable to prevent wrinkling or cracking.

**18.7 WIRE AND CABLE, CABLE ELECTRIC
SHIELDED AND UNSHIELDED, MIL-C-27500**

18.7 Cables, electric, shielded and unshielded, MIL-C-27500.

18.7.1 Introduction. This specification covers the requirements for aerospace electrical cables fabricated from individual wires called out in two basic wire specifications, MIL-W-22759 and MIL-W-81381. Four classifications of cables are covered as follows:

Unshielded, unjacketed - From two to seven color-coded wires, spirally laid without an overall outer jacket

Unshielded, jacketed - From two to seven color-coded wires, spirally laid with an overall outer jacket

Shielded, unjacketed - A single wire, or from two to seven color-coded wires, spirally laid with one or two overall shields

Shielded and jacketed - A single wire, or from two to seven color-coded wires, spirally laid with one or two shields and jackets.

Note that the maximum number of wires in any one cable is seven and all are required to be the same AWG size.

18.7.2 Usual applications. These cables are intended for use in applications requiring wires in a cable configuration for additional versatility and protection. Cables covered by this specification can be used for Grade 1 or Grade 2 applications. Since the outgassing characteristic of the various wires and cables used is not controlled, it is necessary that this property be evaluated for compliance to project outgassing requirements.

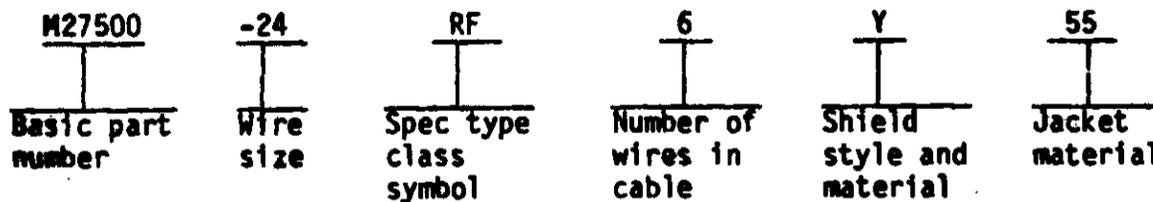
Cables obtained to this specification are intended for low noise or emi control. For example, a twisted pair, triplet, or quad with overall shielding provides excellent reduction of both electromagnetic (low frequency) and electrostatic interference. This is true both for "noisy" power circuits which generate emi and, thus, adversely affect nearby low-noise circuits, and for low-noise circuits themselves. To achieve the maximum noise attenuation, care must be taken to prevent ground loops or circulating currents in the shielding.

Even without shielding, some circuits are sensitive to the relative positions of certain wires in the harness. The relative locations of such wires are maintained when a jacket is shrunk over them in accordance with MIL-C-27500.

Further discussions of the applications of conductor materials and coatings is covered in subsections for MIL-W-22759 and for MIL-W-81381.

18.7.3 Part number designation. Following is the complete part number designation. Note that the color coding of the wires making up the cable must be designated separately because no provision exists for this in the cable part number.

**18.7 WIRE AND CABLE, CABLE ELECTRIC
SHIELDED AND UNSHIELDED, MIL-C-27500**



18.7.4 Physical construction. As noted in 18.7.1, there are four classifications of cables. The maximum number of wires in a cable (all the same AWG) is seven. Descriptions of the construction can be found in MIL-C-27500.

18.7.5 Voltage-withstanding considerations. The capabilities of the individual wires to withstand specified environments is given under the applicable wire specifications. The additional tests called out by this specification refer to the shielding braid, detection of jacket flaws, and dielectric voltage-withstanding capability of the jackets. When two shields are called out, double jackets are required. One jacket is between the shields, to insulate them from each other, and an outer jacket is usually required over the shield.

18.7.6 Environmental considerations. Silver-coated wire is susceptible to cuprous oxide corrosion (red plaque) when stored or used in a moist or high-humidity environment.

18.7.7 Reliability considerations. Because the cables covered by this specification are intended for use in applications which require cabled wire for additional versatility and protection, some additional precautions should be taken to obtain the highest reliability possible. Since a bundle of wires will not bend as sharply and is not as flexible as a single wire, the designer should take care in laying out the path and location of cable bends with proper clearances so that chafing or vibration will not cause a problem. Cable bends should be gradual without kinking. The cable, if it is intended to be flexed, should be clamped or spot bonded as required to prevent any motion during high shock or vibration environments. The selection of TFE, ETFE, FEP, or polyimide wire in shielded cable harnesses depends upon factors such as the environment and material compatibility. Refer to Appendix A of MIL-STD-975 for derating.