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Rev 1 With Change A

Parts Derating Requirements and Application Manual for Navy Electronic Equipment

March 1991

Subj: Parts Application Manual -- Part 1

Foreword

The reliability achieved by military electronic systems and equipments is highly dependent on proper selection and application of the electrical and electronics parts used therein. Chapter I of this document provides requirements for three basic elements of a parts reliability program consisting of: (1) parts derating, (2) part quality, and (3) design for long life. Chapter II contains derating curves and part selection and application information on the ten most commonly used electrical and electronic parts. Appendices provide information on electrical subjects of interest relating to parts application and reliability.

Rapid advances in technology of electronic part and device engineering may cause some of the information contained herein to become outdated. This is especially true of the information contained in sections 100 through 1000 of this document where new military specifications or revisions of those existing are constantly being generated for new parts and new part types. In view of the above, contract and military specifications and standards with their latest applicable revisions should be consulted for selections and applications of parts on a specific contract. In addition, this document will be updated annually in order to reflect the latest available information.

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Listing of Subjects

This document covers the following topics:

Chapter I: Requirements

- Application
- Parts Selection
- Derating
- Design for long life

Chapter II: Parts Application Information and Derating Requirements

- Resistors
- Capacitors
- Discrete semiconductors
- Microcircuits
- Connectors
- Relays
- Crystals
- Switches
- Filters
- Magnetic devices

Appendices: Parts Information on Selected Subjects

- Thermal Considerations for Electronic Component Parts
- Factors Affecting Failure Rates of Parts
- Derating
- Standard Electronic Module Program
- Transient Suppressors
- applicable documents

Introduction

Many equipment item failures are precipitated by stress. When applied stress exceeds the inherent strength of the part, either a serious parametric degradation or a failure will occur. To assure reliability, equipment must be designed to endure stress over time without failure. Parameters which stress a design must be identified and controlled. Parts and materials must be selected which can withstand these stresses. Derating is the selection and application of parts and materials so that applied stress is less than rated for a specific application. The derating criteria in this manual have been developed to provide designers the greatest flexibility possible in applying parts and materials compatible with the need for readiness.

Compliance with these guidelines is a necessary step for institutionalizing the reliability-by-design process and provides an effective means of reducing life cycle cost while increasing readiness.

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Section 700 -- Crystal Units (Quartz) and Crystal Holders (Enclosures)

700 Crystal Units (Quartz) and Crystal Holders (Enclosures)

700.1 General Information

Standard Crystal Units and Holders are specified in MIL-STD-683.

700.2 Application Considerations

700.2.1 ESD Sensitivity

Some crystal units, especially tight tolerance units, are found to be susceptible to electrostatic discharge (ESD) in the static voltage range of 4,000 to 15,000 volts. Surface acoustic wave (SAW) devices are susceptable to ESD damage, induced by static voltages less than 1,000 volts. ESD damage often results in operational degradation rather than catastrophic failure. These units shall be handled according to the requirements of MIL-STD-1686 and DOD-HDBK-263.

700.2.2 Failure Modes

Electrical parameters of piezoelectric crystals are deteriorated by excessive driving current or from high voltages which cause mechanical stress and movement to be generated in the crystal plate. When the voltage is excessive, mechanical forces cause motion in excess of the elastic limit of the crystal and crystal fracture can occur. The fracture can occur as a lifted platelet as has been experienced in lithium niobate SAW delay lines. Such fractures, when occurring in sufficient number, will cause enough change to the operating electrical characteristics, for example, frequency shift, for the crystal to be out of specification.

700.3 Derating Factors

The specified maximum and minimum parameters of the crystal units are limiting factors beyond which the reliability of the crystal unit will be impaired. The designer shall assure that the crystal unit will be operated under conditions that are within the limits specified for the particular unit type required. The principal derating parameter in most applications is Drive Voltage; derate to 50% rated value, or absolute value indicated.

701.1 MIL-C-3098, Crystal Units, Quartz

701.1.1 Application Data

Refer to MIL-STD-683 for characteristics of crystal styles covered by MIL-C-3098.

701.2 MIL-H-10056, Holders (Enclosures), Crystal

701.2.1 Application Data

For Holders to be used with standard crystal units, see MIL-STD-683.

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Chapter II -- Parts Application Information and Derating Requirements

100 Resistors

100.1 General Information

Standard resistors are specified in MIL-STD-199. MIL-STD-199 is the key overall standard for resistor selection; although this standard addresses only selected standard resistors, it should be used to the greatest extent possible. It presents detailed data for use in the design of military equipment. Data is presented on terminology, resistor selection, environmental effects on characteristics and life, applications, application data, failure rates, and aging.

Resistors are functionally classified as fixed and variable (adjustable). Resistor construction is of three general types: composition, film, or wirewound. They basically consist of a resistive element mounted on a base or substrate, an environmental protective coating, and external electrical leads. Composition resistors are made from a mixture of resistive material and a binder, and are molded into a predetermined shape with a specific resistance value. Film resistors are made from a thin resistive film deposited inside or outside an insulating cylinder or filament on which a screw-thread pattern (sometimes called spiral-cut or helix-cut) is scribed to create a thin narrow strip or track of resistive material between the ends of the ceramic or glass substrate. A wirewound resistor is made from resistive wire, wound on an insulative body. These three basic types differ in inherent reliability, size, cost, resistance range, power rating, and general characteristics. No one type has all the best characteristics. Many factors must be considered when choosing among them.

The most important resistor parameters are ohmic value, power handling capacity and tolerance. The power handling capacity normally determines the physical size of the resistor. For example, if an application requires more than one watt, a two watt power wirewound resistor will be the likely choice. If the tolerance needed is ± 2 percent or tighter, the resistor should inevitably be a precision wirewound or film resistor. However, resistor selection depends on specific application and derating program requirements. Some examples:

a. In the design of audio signal voltage amplifiers, circuit operational noise is a significant design parameter; an optimal choice for low-noise resistive circuit elements would be metal film resistors. However, cost considerations may place constraints on the component selection process, mandating use of carbon composition resistors as the circuit element choice.

b. Analog-to-digital and digital-to-analog circuitry requires precise impedance ratio matching and close temperature tracking characteristics; a probable choice in this type of situation would be precision wirewound or precision film resistors.

c. Operational amplifiers (essentially high gain DC amplifiers) require long-term parameter stability (drift-free characteristics); precision wirewound or film resistors would also be a choice in this type application.

The selection of resistor type can be seen as a function of the particular application, cost considerations, program requirements, etc. The purpose of this section is to provide guidelines in choosing the right type for the overall application.

Some of the principal applications for different types of resistors are given in Table 100.1

Some of the typical performance characteristics of different types of resistors can be found in Table 100.2.

Commercial grade, military grade, and military Established Reliability (ER) grade resistors are physically and functionally identical with the exception of failure rate levels. These failure rate levels can vary by orders of magnitude. Whenever possible, an ER resistor, failure rate level of “R” or higher reliability, should be used. Figure 100.1 is a comparison of the predicted part operating failure rates for established reliability resistors. The part operating failure rates shown are derived from the part operating failure rate models in MIL-HDBK-217D. The part operating failure rates are representative of a given military environmental condition and are not necessarily in the same proportion for other environments or operating conditions.

100.2 Application Considerations

100.2.1 Resistor Mounting

Resistor mounting plays a critical role in resistor reliability. The mounting determines how thermal stress, shock, and vibration are transmitted from the environment to the resistor. Mounting guidelines are presented below.

a. Large resistors should be provided with an adequate means for mounting other than the leads. In the presence of vibration or shock, lead failure can occur, and the larger the mass supported by the leads, the more likely leads will fatigue. Even when vibration or shock is not a serious problem, ease of assembly and replaceability considerations suggest that large components be individually mounted. Resistors should be mounted such that the body of the resistor is restrained from movement relative to the mounting base. Bolt-down provisions, plastic ties, metal or plastic clips, or adhesives may be used to secure resistors to the mount base. Also, the heat transfer qualities of the resistor can be enhanced or diminished dependent on clamping heat conduction properties.

b. Maintain lead lengths to a minimum. Leads transfer heat to Printed Circuit Boards (PCB) or other mounting provisions, which act as a heat sink.

c. Where temperature variations are present, leads should be offset bent slightly to allow for thermal contraction and expansion (thermal stress relief).

d. Close tolerance and low-value resistors require special precautions (i.e., short leads and good soldering techniques). The resistance of the leads and the wiring, and a poor solder joint can cause slight (yet significant) changes to the resistance.

e. Special precautions should be taken when resistors are mounted in rows or banks. They should be spaced so no resistor in the row or bank exceeds its maximum permissible hot-spot temperature. Heat dissipation of nearby resistors and restricted ventilation must be taken into account. An appropriate combination of resistor spacing and resistor power rating should be used.

Table 100-1 -- Use Applications of Resistor Types

Resistor Type	**MIL-Spec-No.**	**Application**
Fixed		
Fixed, wire- wound, power type	MIL-R-26	Use where large power dissipation isrequired and where AC performance is relatively unimportant (i.e., when used as voltage divider, bleeder resistors in DC power supplies, or series dropping). They are generally satisfactory for use at frequencies up to 20 kHz even though the AC characteristics are not controlled. Neither the wattage rating nor the rated continuous working voltage may be exceeded
Fixed, wire- wound, power type,	MIL-R-18546	Use where power tolerance and relatively large power dissipation is required for a given unit size and where AC performance is non-critical (i.e., voltage divider, bleeder resistors in DC power supplies, or series dropping circuits).
Fixed, Established Reliability		
Fixed, composition, insulated	MIL-R-39008	Use insulated resistors for general purpose resistor applications where initial tolerance needs to be no closer than ± 5 percent and long term stability needs to be no better than ± 15 percent under fully rated operating conditions.

Fixed, film high stability	MIL-R-55182	Use in circuits requiring higher stability thanprovided by composition resistors or film, insulated, resistors and where AC frequencyrequirements are critical. Operation is satisfactory from DC to 100 MHz. Metal films are characterized by low temperature coefficients and are useable for ambient temperatures of 125ºC, or higher with little degradation.
Fixed, wire- wound, accurate	MIL-R-39005	Use in circuits requiring higher stability than provided by composition or film resistors, and where AC frequency performance is not critical. Operation is satisfactory from DC to 50 kHz.
Fixed, wire- wound, power	MIL-R-39007	Use where power tolerance and relatively larger power dissipation is required for a given type unit size than is provided by MIL-R-26 resistors, and where AC performance is noncritical (i.e., voltage divider, bleeder resistors in DC power supplies, or series-dropping circuits).
Fixed, film, insulated	MIL-R-39017	These film resistors have semi-precision characteristics and small sizes. Design parameter tolerances are loose, but good stability makes them desirable in most electronic circuits.
Fixed, wire- wound, power type, chassis mounted	MIL-R-39009	Use where power tolerance and relatively large power dissipation is required for a given unit size and where AC performance in noncritical (i.e., voltage divider, bleeder resistors in DC power supplies, or series-dropping circuits).
Fixed, film, chip	MIL-R-55342	Use these chip resistors in thin or thick film hybrid circuitry where micro circuitry is indicated.
Variable		
Variable, composition	MIL-R-94	Use where initial-setting stability is not critical and long term stability needs to be no better than± 20 percent.

Variable, wire wound, low operating temperature	MIL-R-19	Use primarily in noncritical, low power, low frequency applications where characteristics of wirewound resistors are more desirable than those of composition resistors.
Variable, wire-wound, power type	MIL-R-22	Use in such applications as motor speed control, generator field control, lamp dimming, heater and oven control, potentiometer uses, and applications where variations of voltage and current are expected.
Variable, wire-wound, precision	MIL-R-12934	Use in servomechanism-mounting applications requiring precise electrical and mechanical output and performance. Used in computer, antenna, flight control, bomb-navigation systems, etc.
Variable, wire-wound, semi-precision	MIL-R-39002	Use for matching, balancing, adjusting circuit variables in computers, telemetering equipment, and other critical applications.
Variable, metal film, non- wirewound	MIL-R-23285	Use where initial-setting stability is not critical and long term stability needs to be no better than ± 5 percent. RVC resistors have low noise and long life characteristics.
Variable, non-wirewound, precision	MIL-R-39023	Use in servomechanism-mounting applications requiring precise electrical and mechanical output and performance. Used in computer, antenna, flight control, and bomb- navigation systems, etc
Variable, wire-wound, adjustment type	MIL-R-27208	Use for matching, balancing, and adjusting circuit variables in computers, telemetering equipment, other critical applications.
Variable, non-wire-wound adjustment type	MIL-R-22097	Use for matching, balancing, and adjusting circuit variables in computers, telemetering equipment, other critical applications.
Variable Established Reliability		
Variable, wire-wound, lead crew	MIL-R-39015	Use for matching, balancing, and adjusting circuit variables in computers, telemetering

actuated		equipment, and other critical applications.
Variable, non-wirewound, adjustment	MIL-R-39035	Use for matching, balancing, adjusting circuit variables in computers, telemetering equipment, and other critical applications.
Special		
Networks, fixed, film	MIL-R-83401	Use in critical circuitry where temperaturestability, long life, reliable operation, andaccuracy are of prime importance. They are particularly desirable in applications where miniaturization is important. They are also useful where a number of resistors of the same resistance values are required in the circuit.

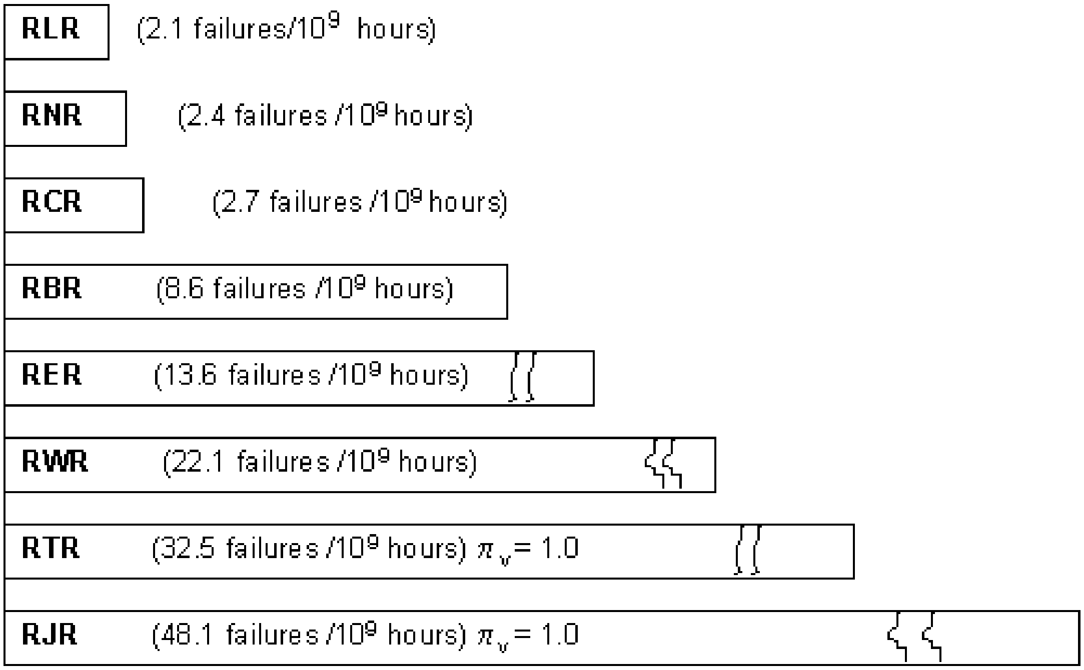
Table 100-2 -- Typical Performance Characteristics of Various Resistor Types

Characteristics	**Carbon Composition**	**Carbon Film**	**Metal Film**	**Power Wirewounds**	**Precision Wirewound**
Resistance Range	2.7 ohm to100 M-ohm	10 ohm to25 M-ohm	10 ohm to3 M-ohm	0.1 ohm to150 k-ohm	0.1 ohm to273 k-ohm
PowerRating (W)	1/8 to 2	1/10 to 2	1/20 to 2	5 to 255	1 to 15
Initial Tolerance	20% to 5%	10% to 2%	1% to 0.1%	10% to 5%	1% to 0.05%
Temperature coefficient resistance(TCR)	±200 to±1500	±200 to±500	100 typ	Less than±260	±50 typ
Resistance change after over-voltage (2-1/2 times rated for5 s)	0.5% typ	1% type	Figures not available	2% max	0.2% max
Noise (resistance below 1 Mohm)	Less than6 V/V^4	Less than10 V/V	Less than0.1 V/V	Not applicable	Not applicable

Operating frequency	Up to1 Mhz	Up to100 Mhz	Up to400 Mhz	Limited to audio freq.	Limited to audio freq.
Stability per MIL specs Resistance changes from Moisture(1) High temp(2) Load life(3)	MIL-R-39008 6% typ-2.0 to 10.1%-3.0% typ	MIL-R-55182 0.3% 2.0% 0.5%	MIL-R-39017 0.4% 0.5% 0.5%	MIL-R-390070.5 %0. 5% 3% max	MIL-R-39005 0.2% 0.5% 0.5%
Relative cost	Least expensive	Moderately expensive	Moderately expensive	Moderately expensive	Most expensive

1. Temporary resistance change from nominal value at 25ºC when resistor is brought to 105ºC.
2. 240 hours at 95 percent relative humidity and 40ºC.
3. Load life is 1000 hours at rated voltage and ambient temperature.
4. Depends on manufacturing process. Hot-molded carbon composition resistors provide lower noise level values than other carbon composition resistors, but at a higher cost.

Caution: These values are given for illustration purposes only and shall not be considered absolute. The exact failure rate depends on the maximum temperature rating and resistance value



Note: For RTR and RJR resistors, = π_{TAPS} = 1.24.

*Figure 100.1 -- Relative Part Operating Failure Rates for Established Reliability Type Resistors (Predipcted)**

***Establishment of Ratios*:**

MIL-HDBK-217 Prediction Method
  Naval Sheltered environment
  Ambient temperature (T_A) = 70ºC
  Stress ratio (S) = 0.1
  Failure rate level = "P"
  Resistance factor = 1
  v = Voltage factor
  TAPS -- Potentiometer taps factor

f. For resistors mounted in series, consider the heat being conducted through the leads to the next resistor.

g. Large power resistors should be mounted to the metal chassis for heat dissipation.

h. Do not mount resistors with power dissipation 1 Watt directly on terminal or printed wiring boards without use of heat sinks. A resistor that dissipates over one watt can damage a terminal board. A damaged board will have a lower insulation resistance.

i. For the most efficient operation and even heat distribution, power resistors should be mounted in a horizontal position.

j. Consider proximity to other heat sources as well as self-heat.

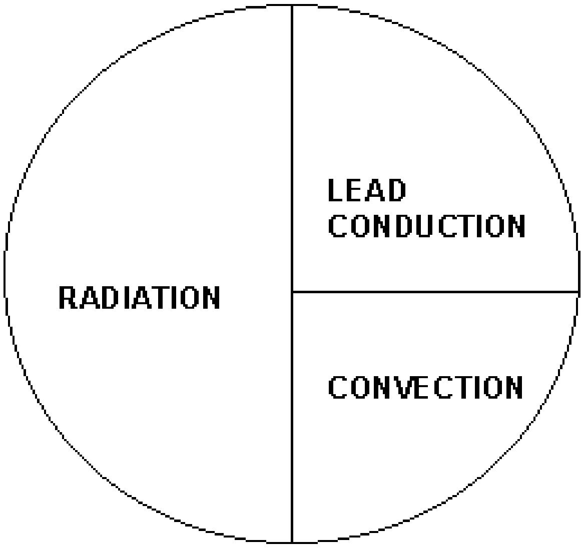
k. Select mounting materials that will not damage, and design mounts that will withstand strain due to thermal expansion and contraction.

l. Supplementary insulation should be used if a resistor normally mounted directly onto a chassis is used at a higher potential above ground than is specified for the resistor. However, the mounting must continue to dissipate generated heat.

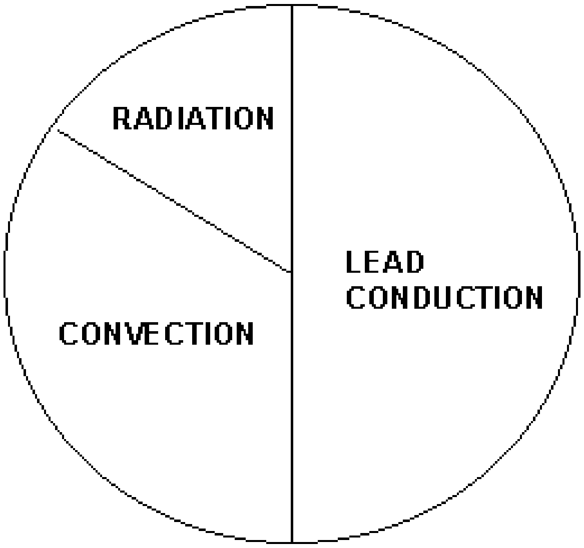
m. Assembly techniques can affect resistor reliability. Resistors should never be overheated by excessive soldering-iron heat, and the resistor leads should not be abraded by assembly tools. Normal soldering practice should include heat sinking so that the resistor will not be physically damaged or its resistance value changed by the soldering operation.

100.2.2 Temperature Effects

Inadequate heat dissipation is the predominant cause of failure for any resistor type. Figure 100.2 portrays heat dissipation from fixed resistors in free air. The lowest possible resistor surface temperature should be maintained using radiation, conduction, and convection as much as possible. Under normal atmospheric conditions (25ºC, 30 in. Hg), resistors up to 2 watts dissipate heat in the following proportions: 10 percent radiation, 40 percent convection, and 50 percent conduction through leads. Resistors with substantially larger wattage ratings, by virtue of increased surface area, dissipate heat in proportions of: 50 percent radiation, 25 percent convection and 25 percent conduction through leads.



Resistors Above 2 Watts



Resistors 2 Watts and Below

Figure 100.2 -- Heat Dissipation of Resistors Under Room Conditions

Thermal dissipation considerations for the three methods of heat transfer are:

a. Radiation considerations:

    (1) Maximize spacing between resistors that generate large amounts of heat. This will reduce cross-radiation heating effects.

    (2) Place resistors so that any adjacent large metallic areas can absorb significant amounts of radiated heat.

    (3) Use vented or similar types of body clamps on larger size resistors.

b. Conduction considerations:

    (1) Use resistors with thick leads and minimum length.

    (2) Terminate resistor leads at tiepoints and leave in mass to act as heat sinks.

    (3) Mount large size resistors with body clamps to large metallic masses (such as the chassis).

c. Convection considerations:

    (1) Reduce resistance to air flow by maximizing spacing between resistors that generate large amounts of heat.

    (2) Orient resistors properly and provide baffles where needed for exposure to air flow.

Power dissipation per unit of resistor area is specified in MIL-STD-199. The surface temperature rise of specific resistor types can usually be obtained from vendor resistor specifications.

100.2.3 Form Factors and Preferred Resistance Value

For physical form and preferred resistance values of each resistor style, see MIL-STD-199 or the appropriate resistor detailed military specification.

100.2.4 Variable Resistors

The use of variable resistors is not preferred for high reliability applications. These resistors are not hermetically sealed. Therefore, their performance can degrade due to the ingestion of soldering flux, cleaning solvents, and conformal coatings during production. Variable resistors also contain moving parts that wear with use. The reliability of variable resistors is lower than fixed resistors. In the event that variable resistors must be used, the following precautions should be followed:

a. Enclosed units should be used to keep out as much dust and dirt as possible and to protect the mechanism from mechanical damage. Also lubrication oil can cause dust or wear particles to concentrate within the unit.

b. Provide some method of preventing undesired movement of the wiper arm during vibration and shock. For resistors not in continuous use, the short locked shaft with a slotted end is preferred. For continuous use, the high torque shaft is preferred. If it is absolutely necessary to have a long shaft, a coupled extension is preferred to one long integral shaft. Regardless of the type of shaft, oversize control knobs which permit high rotational torque will generally result in damage to the integral stop. Use the smallest size knob to reduce applied torque.

c. When a variable linear resistor is being used as a voltage divider, the output voltage through the wiper will not vary linearly if current is being drawn through it. This characteristic is called "loading error." To reduce the loading error, the load resistance should be at least 10 to 100 times greater than the end-to-end potentiometer resistance.

d. Both the load current as well as the "bleeder" current will be flowing through a part of the resistor. It is useful to remember that both will contribute to the heating effect.

100.2.5 Composition Resistor Application Considerations

Composition resistors are small, inexpensive, and have good reliability when properly used. Their liabilities are: poor resistance stability, high noise characteristics, and appreciable voltage and temperature coefficients. They do, however, have good high-frequency characteristics although this characteristic is not controlled by specification. Other application considerations include:

a. Exposure to humidity may have two effects on resistance characteristics.

    (1) Surface moisture can result in leakage paths which will lower resistance, or

    (2) absorption of moisture into the element may increase resistance as well as to allow the transport of ions and/or chemicals which may degrade reliability. These phenomena are more noticeable in higher resistance ranges. Resistance values can change by up to 15 percent if the resistor is exposed to humid atmosphere or operated at low power levels. Resistance may also change during shelf storage, shipping, or if the equipment is not operated for long periods of time.

b. Resistor characteristics can be permanently changed or degraded by exposure to high operating temperatures.

c. The resistance-temperature characteristic for composition resistors is higher than other resistor styles covered by military specifications.

d. Avoid using these resistors in low power level high resistance (1 M-ohm or more) circuits. Thermal agitation (Johnson noise) and resistance fluctuations (carbon noise), present only during current flow, are characteristic of this type of resistor. The expected noise level is about 3 to 10 mV/V. A film or wirewound resistor will usually provide lower noise levels.

e. When used in high frequency circuits (1 MHz and above), the effective resistance will decrease as a result of dielectric losses and shunt capacitance (both end-to-end and distributed capacitance to mounting surface). High frequency characteristics are not controlled by specification and hence are subject to change without notice.

f. Care should be taken in soldering resistors. Several properties may be seriously affected by excess heat. The length of lead left between the resistor body and the soldered point should not be less than 1/4 inch. Heat-dissipating clamps should be used, if necessary, when soldering resistors in close quarters. In general, if it is necessary to unsolder a resistor, discard the old resistor and use a new one.

g. Fixed composition resistors exhibit little change in effective DC resistance up to 100 kHz. Resistance values above .3 megohms start to decrease in resistance at approximately 100 kHz. Above a frequency of 1 MHz, all resistance values exhibit decreased resistance. However, the resistor operates as a pure resistance free from a reactive component into the MHz region.

h. Nominal minimum resistance tolerances available for fixed composition resistors are ± 5 percent. Combined effects of climate and operation on unsealed types can raise this tolerance to ± 15 percent. These effects include aging, pressure, temperature, humidity, and voltage gradient.

i. Composition elements of variable resistors can wear away after extended use, leaving particles of the element to permeate the mechanism. This can result in warmer operation and high resistance shorts within the variable resistor.

j. These variable resistors should not be used at potentials to ground or case greater than 500 volts peak, unless supplementary insulation is provided.

100.2.6 Film Resistor, General Application Considerations

a. Film-type resistors have the best high-frequency performance of all resistor types. The effective DC resistance for most resistance values remains fairly constant up to 100 MHz and decreases at higher frequencies. In general, the higher the resistance value the greater the effect of frequency.

b. Some lower power, tighter tolerance film resistors are quite susceptible to electrostatic damage (see MIL-STD-1686 and DOD-HDBK-263).

c. Film resistors are recommended where high stability and close tolerance resistance is required. Their resistance value can be accurately maintained over a broad range of temperatures and for long periods of time. Regardless of the purchase tolerance (nominally ± 1 percent or less), the design should be able to tolerate a ± 2 percent shift in resistance to assure long life reliability in military applications.

d. Operation at radio frequencies above 100 MHz can produce inductive effects on spiral-cut types; skin inductive effects, however, are negligible.

e. The resistance-temperature characteristic of film resistors is fairly low (± 500 PPM/ºC and ± 200 PPM/ºC) for thick film (RLR), and very low (± 25 PPM/ºC) for metal film types (RNR). Metal film resistors can experience temporary or permanent changes in resistance when operating in the presence of extreme temperatures.

f. Film resistors are capable of tight tolerance and high stability. Minimum resistance tolerance available is 0.1 percent.

g. Exposure to moisture can seriously affect this type of resistor if not protected by molded or ceramic casing or internal deposition of the resistance element.

h. Carbon-film resistance elements are susceptible to physical damage, hermetic seals are preferred for film-type resistors.

I. The noise level of variable film resistors is quite low compared to variable composition resistors.

j. The resistance values of variable film resistors are sensitive to shock, acceleration, and high frequency vibration force. They may vary up to 6 percent. The design should be able to tolerate a variation in resistance at the contact arm when the shaft is unlocked.

k. Resistance is somewhat sensitive to temperature rise and ambient temperature of variable film resistors under operation. This effect should be addressed during design in order to allow for such resistance changes. The resistance-temperature characteristic is measured between the two end terminals. Whenever resistance-temperature characteristic is critical, variation due to the resistance of the movable contact should also be considered.

100.2.7 Wirewound Resistor, General Application Considerations

a. Many wirewound resistors are constructed using reverse Pi-winding, Ayrton-Perry, or bifilar winding to reduce inductance. However, they are not designed for high frequency applications. They are especially suited for use in DC amplifiers, electronic computers, meters, and laboratory test equipment. If used in high frequency circuits, caution must be taken to assure satisfactory performance.

Wirewound resistors are not recommended for use above 50 kHz. Wirewound resistors usually exhibit an increase in resistance with high frequencies because of skin effect.

b. Applied voltages in excess of the resistor maximum voltage rating can cause insulation breakdown in the thin coating of insulation between the windings.

c. The use of tapped resistors should be avoided. Tap insertions weakens the resistor mechanically and lowers the effective power ratings.

d. Moisture may degrade the coating or potting compounds used in these resistors.

e. Wirewound resistors using a plastic or ceramic bobbin are sensitive to mechanical damage from vibration, shock, and pressure.

f. Due to their size and weight, the bodies of these resistors should be constrained from movement in high frequency vibration and shock environments.

g. Wirewound power resistors have high stability, a medium temperature coefficient, high reliability, a negligible voltage coefficient, poor high-frequency characteristics, negligible noise, and are capable of dissipating considerable heat.

h. Wirewound, accurate resistors are physically large compared to composition types of the same power rating. They usually exhibit very high stability, negligible voltage coefficient, and high-frequency characteristics probably good to 50 kHz maximum. Operation above 50 kHz may produce inductive effects and intra-winding capacitive effects.

i. Wirewound resistors are used where high cost and size are not major design constraints and where the operating environment can be controlled.

j. Wirewound power variable resistors are generally not available with low tolerances. This is because most wirewound resistor applications do not require accurate resistance.

k. Fixed, wirewound, accurate resistors are physically the largest of all types for a given resistance and power rating, since they are very conservatively rated.

l. The variable wirewound resistor produces more noise than any other variable resistor. This is due to the stepping of the contact from wire to wire.

m. Variable wirewound resistors have the lowest temperature coefficient and the most stable characteristics of any potentiometer.

100.3 Derating Factors

For high reliability, resistors shall be derated according to the derating requirements specified herein. The resistor operating temperature range shall be compatible with the equipment operating temperature. Hermetically sealed resistors should be used in environments where high relative humidity may be encountered, since exposure to humidity can have two effects on resistance values. For wirewound and composition high value resistors, surface moisture can result in lowering resistance, or absorption into the resistive element can increase resistance.

In AC applications the rms (root-mean-square) values of voltage or current are used to determine the effective power to be used in reliability and derating calculations.

For all resistors, the stress ratio S is calculated as:

$$\mathbf{S = \frac{P\ (Applied)}{P\ (Rated)}}$$

100.4 Rating Under Pulsed Conditions and Intermittent Loads.

In those instances in which the resistor is used in circuits where power is drawn intermittently or in pulses, the actual power dissipated with safety during the pulse can sometimes exceed the steady state power rating of the resistor.

Resistor heating is determined by the duty factor and the peak power dissipated. The thermal time constant (the time required for a 63.2 percent delta between initial and final body temperature) of the resistor must be determined, and pulse power limited to that value which will not result in a temperature rise greater than allowed by the steady state derating criteria defined herein. For repetitive pulses, the average power must not exceed the derated limits defined herein. For short and nonrepetitive pulses, the temperature rises must be calculated.

Additional considerations to be included during pulse rating assessments are:

a. The voltage applied during the pulse must not exceed 70 percent of the dielectric breakdown voltage rating of the resistor, after derating for the maximum altitude specified for the equipment operation.

b. The circuit design must preclude a failure that would permit continuous application of excessive power to the resistor.

c. Components with welded connections can withstand much higher peak currents than those with pressure connections. Accordingly, peak power applied to film resistors must not exceed four times the derated value permitted for steady state operation. Carbon composition resistors, because of the permissible variation in resistor value, can accommodate greater peak power dissipations than the more stable resistors. Therefore, peak power dissipation in carbon composition resistors must be limited to a maximum of 30 times the derated value allowed for steady state operation.

101 Resistors, Fixed

101.1 MIL--R--26, Resistors, Fixed, Wirewound (Power Type), (Style RW)

101.1.1 Application Considerations

101.1.1.1Substitution

Use MIL-R-39007 style RWR resistors instead of MIL-R-26 style RW when feasible.

101.1.1.2Operating Temperature

The maximum operating temperature should be limited to 200ºC. Above 200ºC, the resistor is subject to outgassing of the volatile materials used in the fabrication process.

101.1.2Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.3.

b. Pulse condition -- This resistor is not suitable for pulsed circuits (voltage or current pulse amplifiers, or pulse wave shaping circuitry).

Note: In pulse network applications, use Average Power = (Peak Pulse Power) (Pulse Repetition Frequency) (Pulse Width) and derate accordingly.

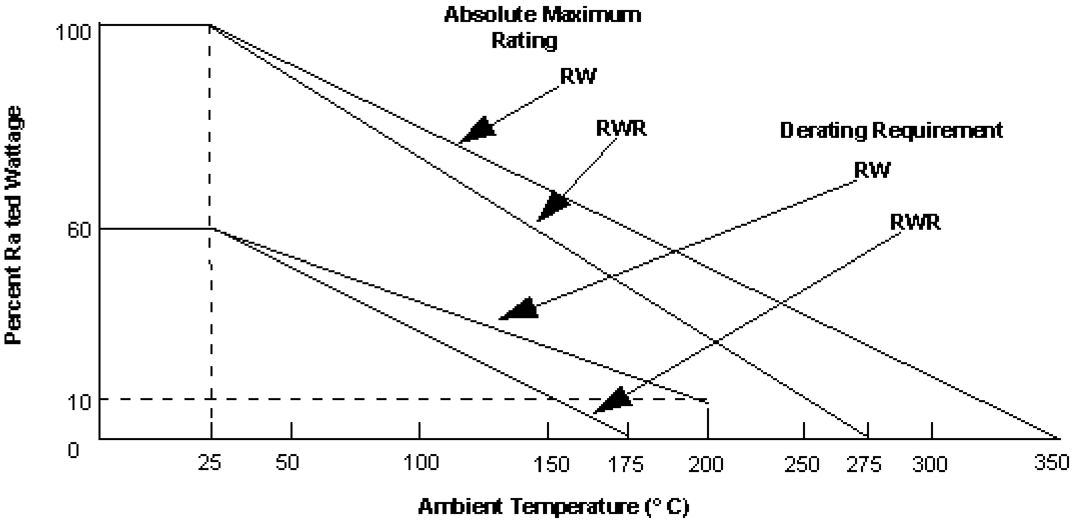


Figure 100.3 -- Derating Requirements for Styles RW29, 31, 33, 35, 37, 38, 47, 56 And RWR78, 80, 81, 82, 84, 89

101.2 MIL--R--18546, Resistors, Fixed, Wirewound, (Power Type, Chassis Mounted), (Style RE)

101.2.1 Application Considerations

101.2.1.1 Substitution

Use MIL-R-39009 style RER resistors instead of MIL-R-18546 style RE when feasible.

101.2.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.4.

b. Pulse conditions -- When using this resistor in pulsed circuit applications, the following two conditions shall be met:

(1) Average power should be less than or equal to the maximum allowable derated power as shown in Figure 100.4.

(2) Peak voltage should not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-18546).

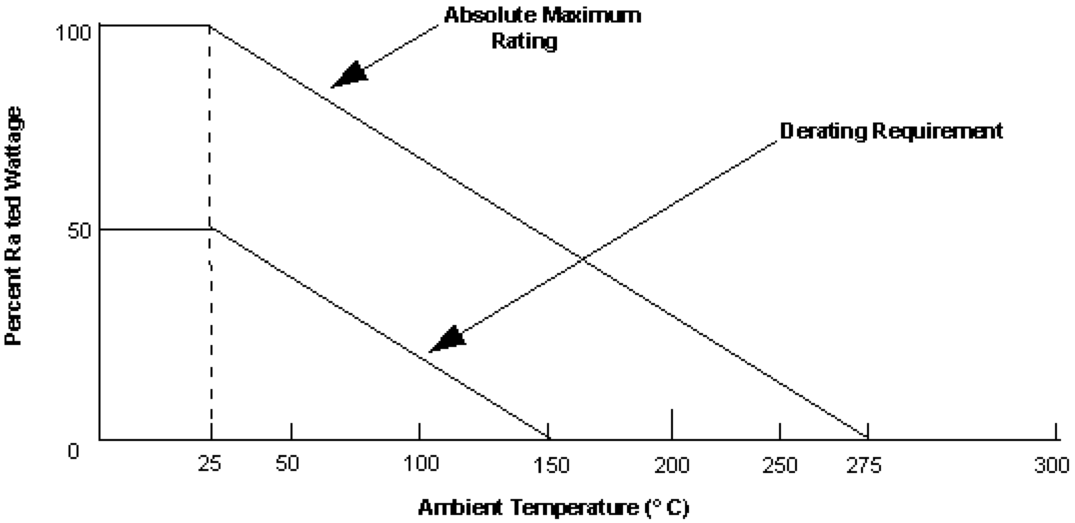


Figure 100.4 -- Derating Requirements for Styles RE77, 80 and RER40, 45, 50, 55, 60, 65, 70, 75

102 Resistors, Fixed, Established Reliability

102.1 MIL--R--39008, Resistors, Fixed, Composition (Insulated), Established Reliability, (Style RCR)

102.1.1 Application Considerations

102.1.1.1 Voltage Coefficient

For a resistance greater than 1,000 ohms, values can change with the applied voltage, as follows:

RCR050.05	**percent/volt**
RCR07, RCR200.035	**percent/volt**
RCR32, RCR420.02	**percent/volt**

The voltage coefficient for resistors rated below 1,000 ohms is not controlled by specification. These resistors should not be used in circuits which are sensitive to this parameter.

102.1.2 Derating Requirements

a. Steady-state conditions -- When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.5.

b. Pulse conditions -- When using these resistors in pulse circuit applications, the following conditions shall be met:

   (1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.5.

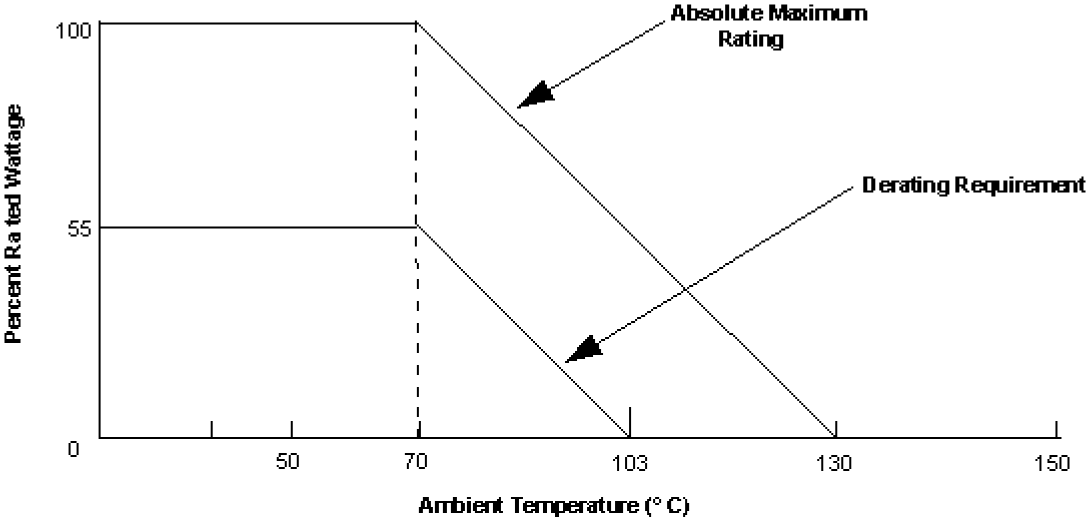


Figure 100.5 -- Derating Requirements for Styles RCR05, 07, 20, 32, 42

Note: In pulse network applications, use Average Power = (Peak Pulse Power) (Pulse Repetition Frequency) (Pulse Width) and derate accordingly.

   (2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less, as specified by the appropriate resistor military specification (MIL—R--39008).

102.1.3 Quality Level

Only ER level “R” or higher shall be used.

102.2 MIL--R--55182, Resistors, Fixed, Film, Established Reliability, (Style RNR)

102.2.1 Application Considerations

102.2.1.1 High Frequency Applications

When used in high frequency circuits (400 MHz and above), the effective resistance will decrease as a result of shunt capacitance (both end-to-end and distributed capacitance to mounting surface). High frequency characteristics of metal film resistors are not controlled by specification and are subject to change without notice.

102.2.1.2 Noise

Noise output is controlled by the specification. In applications where noise is an important factor, fixed film resistors are superior to composition types. Where noise test screening is indicated, it is recommended that the noise test procedure of MIL-STD-202 be used.

102.2.2 Derating Requirements

a. Steady-state conditions -- When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.6.

b. Pulse conditions -- When using these resistors in pulse circuit applications, the following conditions shall be met:

   (1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.6.

   (2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-55182).

   Note: In pulse network applications, use Average Power = (Peak Pulse Power) (Pulse Repetition Frequency) (Pulse Width) and derate accordingly.

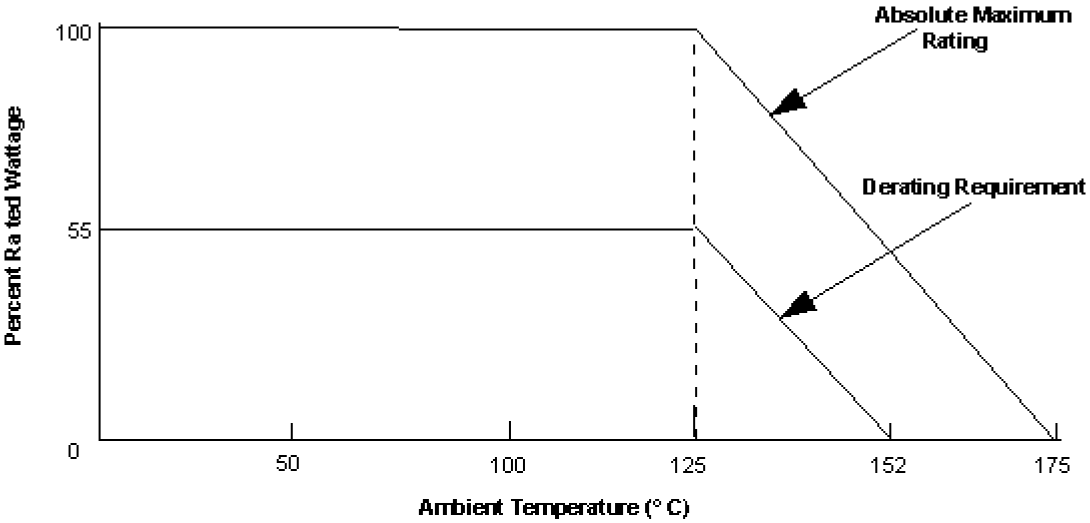


Figure 100.6 -- Derating Requirements for Styles RNR50, 55, 60, 65, 70, 75 and RNC90

102.2.3 Quality Level

Only ER level "R" or higher shall be used.

102.3 MIL--R--39005, Resistors, Fixed, Wirewound (Accurate), Established Reliability, (Style RBR)

102.3.1 Application Considerations

These resistors are intended for use where extremely close tolerances (± 1 percent to ± 0.01 percent), long life, and high temperature stability is required.

102.3.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.7.

b. Pulse conditions -- When using these resistors in pulse circuit applications, the following conditions shall be met:

  (1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.7.

  (2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-39005).

  Note: In pulse network applications, use Average Power = (Peak Pulse Power) (Pulse Repetition Frequency) (Pulse Width) and derate accordingly.

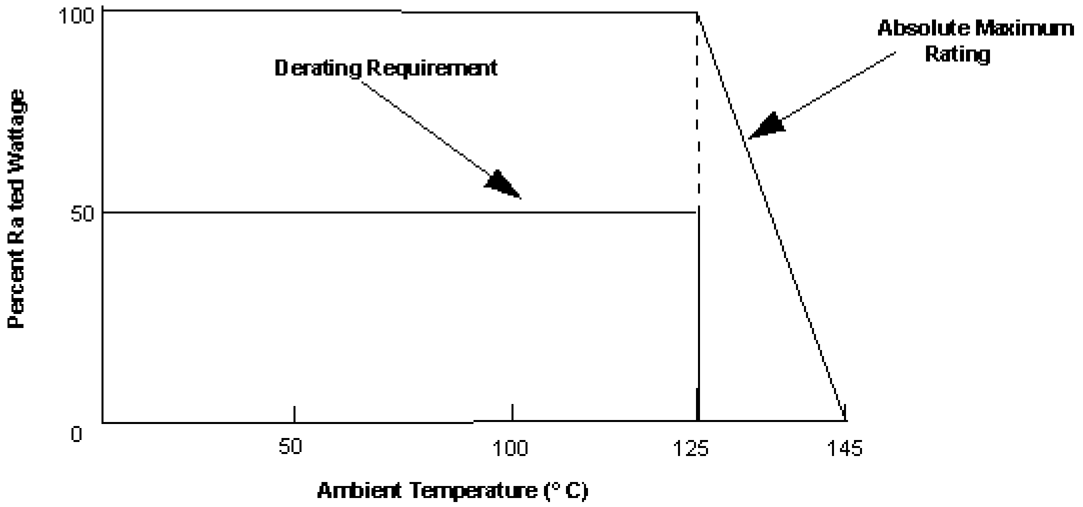


Figure 100.7 -- Derating Requirements for Styles RBR52, 53, 54, 55, 56, 57, 71, 75

102.3.3 Quality Level

Only ER level “R” or higher shall be used.

102.4 MIL--R--39007, Resistors, Fixed, Wirewound (Power Type), Established Reliability, (Style RWR)

102.4.1 Application Considerations

These resistors are recommended for use where greater power handling capacity is required. The RWR resistors are available in very close tolerance (to + 0.1 percent) and have tightly controlled temperature coefficients (+ 20 PPM/ºC). Regardless of purchase tolerance, the design should tolerate a + 1 percent shift in resistance value to assure long life reliability in military applications.

102.4.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.3.

b. Pulse conditions -- When using these resistors in pulse circuit applications, the following conditions shall be met:

   (1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.3.

   (2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-39007).

102.4.3 Quality Level

Only ER level “R” or higher shall be used.

102.5 MIL--R--39017, Resistors, Fixed, Film (Insulated), Established Reliability (Style RLR)

102.5.1 Application Considerations

102.5.1.1 Resistance Tolerance

These resistors are recommended for use where very close tolerances are not required, or where composition type resistors do not provide the needed accuracy or stability. Regardless of the purchase tolerance (i.e., + 1 percent or + 2 percent), the design should tolerate an additional + 5 percent shift in resistance value to assure long life reliability in military applications.

102.5.1.2 Operating Frequency

These resistors perform well in high frequency applications (up to about 100 MHz). The resistance versus frequency characteristics are as shown in Figure 100.8.

102.5.1.3 Noise

The noise generated by these resistors is relatively low.

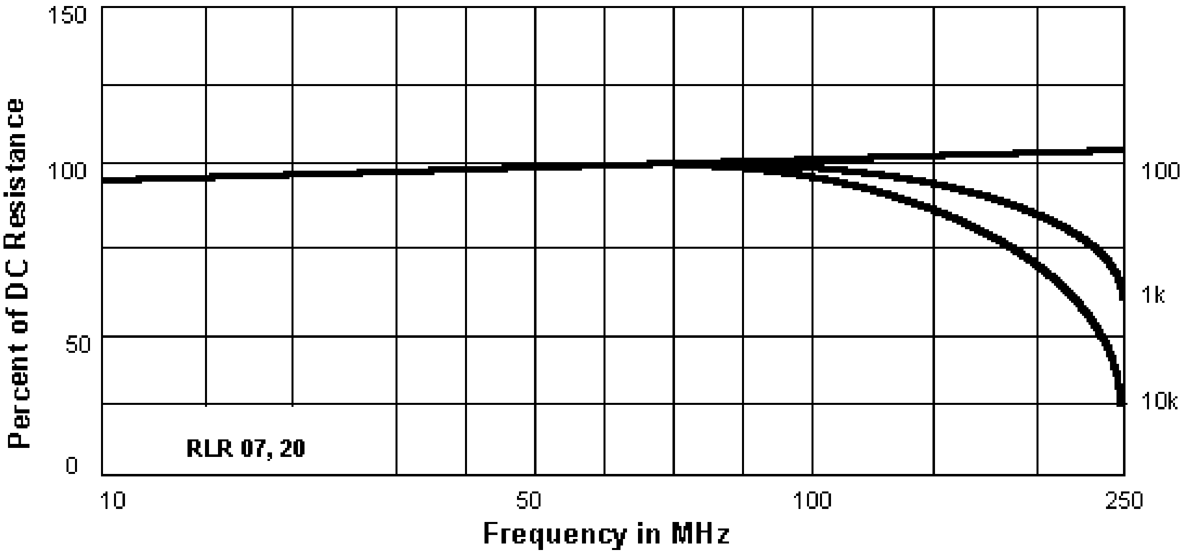


Figure 100.8 -- Response Curve

<u>102.5.2 Derating Requirements</u>

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.9.

b. Pulse conditions -- When using these resistors in pulse circuit applications, the following conditions shall be met:

   (1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.9.

   (2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-39017).

   Note: In pulse network applications, use Average Power = (Peak Pulse Power) (Pulse Repetition Frequency) (Pulse Width) and derate accordingly.

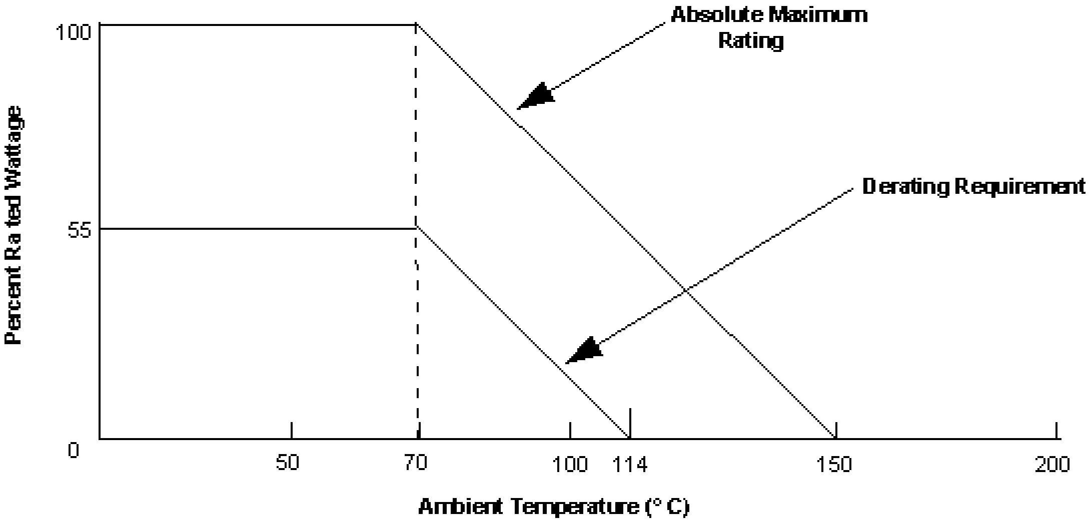


Figure 100.9 -- Derating Requirements for Styles RLR05, 07, 20, 32

102.5.3 Quality Level

Only ER level "R" or higher shall be used.

102.6 MIL--R--39009, Resistors, Fixed, Wirewound, Power Type, Chassis Mounted, Established Reliability (Style RER)

102.6.1 Application Considerations

102.6.1.1 Resistance Tolerance

Only one tolerance range (+ 1 percent) is available. The temperature stability is very good (+ 30 ppm/ºC). The design should tolerate a + 1.5 percent shift in resistance value to assure long life reliability in military applications.

102.6.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.4.

b. Pulse conditions -- When using these resistors in pulse circuit applications, the following conditions shall be met:

   (1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.4.

   (2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-39009).

102.6.3 Quality Level

Only ER level “R” or higher shall be used.

102.7 MIL--R--55342, Resistors, Fixed, Film, Chip, Established Reliability (Style RM)

102.7.1 Application Considerations

102.7.1.1 Use

These chip resistors are intended to be used in thin or thick film hybrid circuitry where micro circuitry is indicated.

102.7.1.2 Mounting

These resistors may be mounted individually on a substrate, usually 95 percent alumina, and connected to conductor areas by means of solder pre-forms, conductive cement, or wire bonding. They can also be directly connected to other components on the same substrate by means of wire bonding, using the substrate as a base or carrier for the resistor.

102.7.1.3 Stacking of Resistors

Stacking of resistors should be avoided, since experience has shown that failure can occur due to electrolytic action in the bonding adhesive. In the event that packaging considerations do include stacking, compensation for lower heat dissipation capabilities is required by properly derating the wattage rating. Stacking of resistors requires procuring activity approval.

102.7.1.4 Electrostatic Damage Sensitivity

Most types of film devices are found to be susceptible to electrostatic discharge (ESD) damage.

102.7.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.10.

b. Pulse conditions -- When using these resistors in pulse circuit applications, the following conditions shall be met:

   (1) The average power shall be less than or equal to the maximum allowable derated power as shown in Figure 100.10.

   (2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-55342).

   Note: In pulse network applications, use:
   Average Power = (Peak Pulse Power)(Pulse Repetition Frequency)(Pulse Width) and derate accordingly.

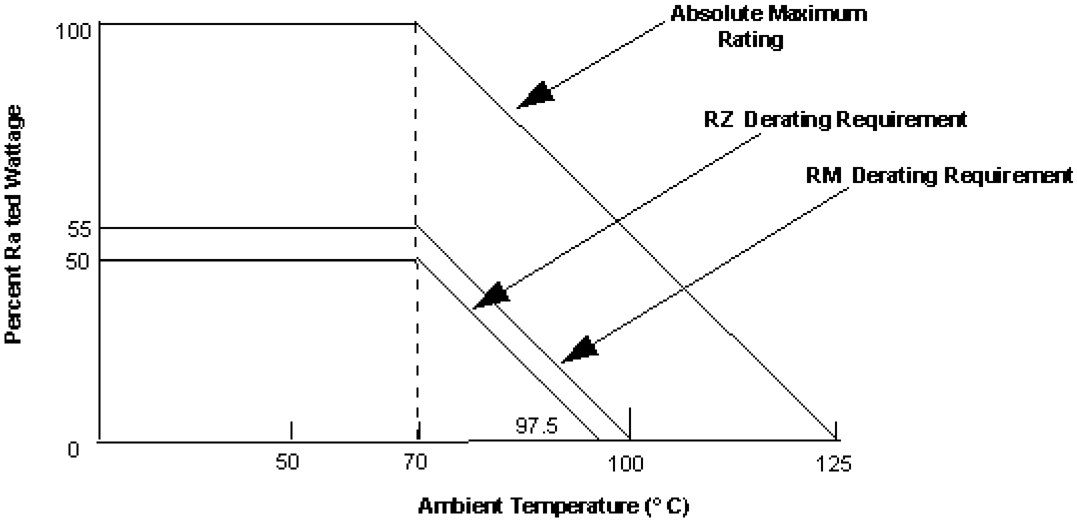


Figure 100.10 -- Derating Requirements for Styles RM1005, 1505, 2208 AND RZ010, 020, 040, 050

<u>102.7.3 Quality Level</u>

Only ER level "R" or higher shall be used.

<u>103 Resistor, Variable</u>

103.1 MIL--R--94, Resistors, Variable, Composition (Style RV)

<u>103.1.1 Application Considerations</u>

103.1.1.1 Selection of Mount Bushing

Four types of mount bushings are available:

N	**Standard**
L	**Locking**
S	**Shaft and Panel Sealing (Standard)**
T	**Shaft and Panel Sealing (Locking)**

It is recommended that S bushings be used due to longer rotational life.

103.1.1.2 Shelf Life

An average resistance change (R) of 20 percent per year under normal storage conditions is estimated.

103.1.1.3 Temperature Characteristics

An average change of ± 8 percent due to thermal cycling is estimated.

103.1.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.11.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

Caution For styles rv reduce the max allowable derating curve if the entire element is not used.

Note: For potentiometer applications, it is necessary to consider both load and bleeder current in determining resistor power dissipation.

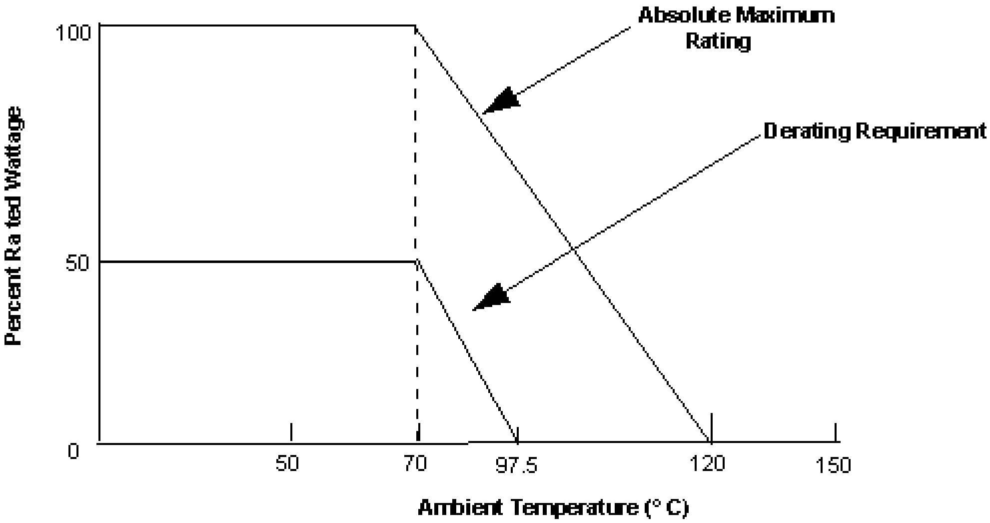


Figure 100.11 -- Derating Requirements for Styles RV04, 06

103.2 MIL--R--19, Resistors, Variable, Wirewound (Low Operating Temperature) (Style RA)

103.2.1 Application Considerations

103.2.1.1 Selection of a Safe Resistor Style

The wattage ratings of these resistors are based on operation at 40ºC, mounted on a 16 gauge steel plate, 4 inches square. This mounting technique should be taken into consideration when the wattage is applied during specific applications. For other types of mountings, the ratings must be properly modified. The wattage rating is applicable when the entire resistance element is operational in the circuit. When only a portion is engaged, the wattage is derated proportionately.

103.2.1.2 Linear and Nonlinear Tapers

As shown in Figure 100.12, Taper A is a linear resistance taper, which is one having a constant change of resistance with angular rotation, while Taper C is a nonlinear resistance taper, which has a variation in the change of resistance with angular rotation.

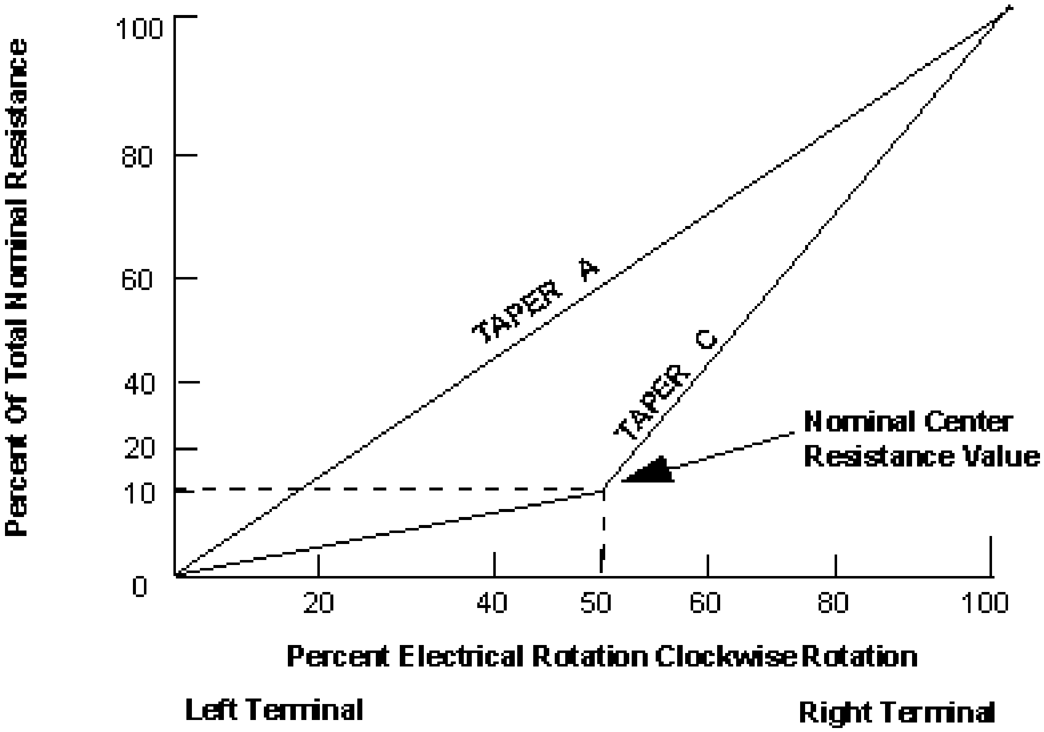


Figure 100.12 -- Linear and Nonlinear Tapers for RA Resistors

<u>103.2.2 Derating Requirements</u>

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.13.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

<u>Caution</u>**:** For styles RA reduce the max allowable derating curve if the entire element is not used.

Note: For potentiometer applications, it is necessary to consider both load and bleeder current in determining resistor power dissipation.

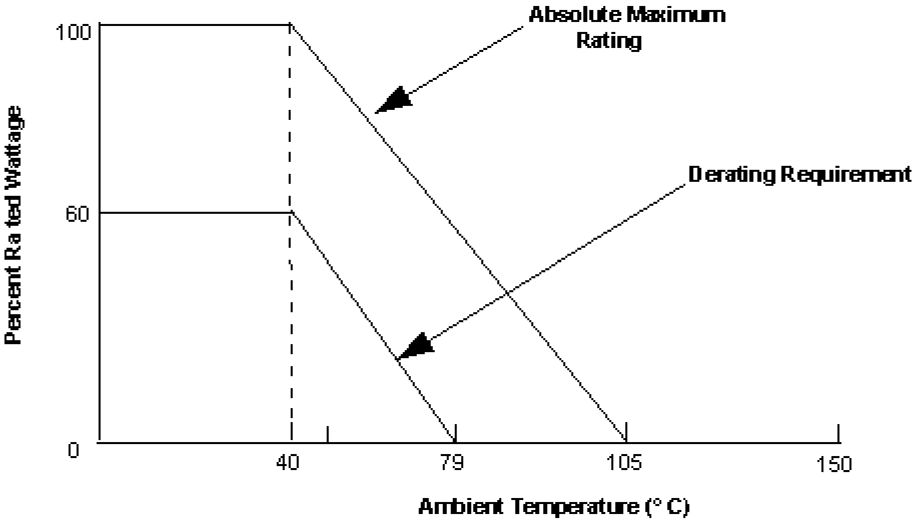


Figure 100.13 -- Derating Requirements for Styles RA20, 30

103.3 MIL--R--22, Resistors, Variable, Wirewound (Power Type), (Style RP) (Unenclosed)

103.3.1 Application Considerations

103.3.1.1 Selection of a Safe Resistor Style

The wattage ratings of these resistors are based on operation at 25ºC, mounted on a 12 inch square steel panel, .063 inch thick (4 inch square x 0.050 inch for RP05 and RP06). This mounting technique should be taken into consideration when wattage is dissipated during specific applications. For other types of mountings, the ratings should be properly modified.

103.3.1.2 Supplementary Insulation

These resistors should not be used at potentials above ground greater than 500 volts (250 volts for RP05 and RP06) unless supplementary insulation is used.

103.3.1.3 Electrical Off Position

Care should be taken in specifying the electrical off position when resistors are required to turn off DC circuits having potentials in excess of 40 volts.

103.3.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.14.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

Caution: for styles rp reduce thenote: operation of these resistors max allowable derating at ambient temperatures greater curve if the entire than 125ºC can damage metal elementis not used. plating, shaft lubrication, insulation, etc., Of resistors.

Note: Operation of these resistors at ambient temperatures greater than 125°C can damage metal plating, shaft lubrication, insulation, etc., of resistors.

Note: For potentiometer applications, it is necessary to consider both load and bleeder current in determining resistor power dissipation.

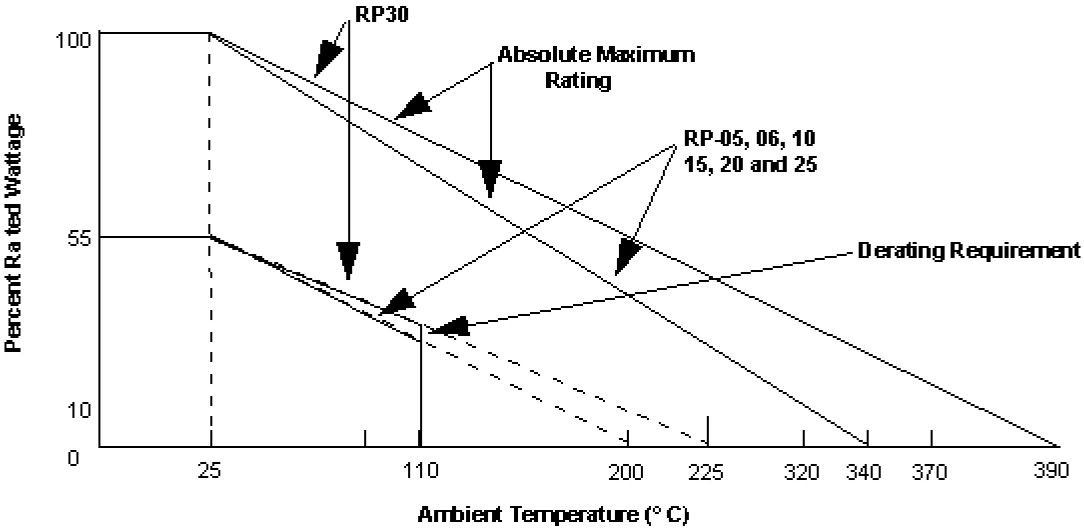


Figure 100.14 -- Derating Requirements for Styles RP05, 06, 10, 15, 20, 25, 30

103.4 MIL12934, Resistors, Variable, Wirewound, Precision, (Style RR)

103.4.1 Application Considerations

103.4.1.1 Selection of a Safe Resistor Style

The wattage rating of these resistors is based on operations at 85ºC, mounted on a 4 inch square, 0.25 inch thick alloy aluminum panel. This mounting technique should be taken into consideration when wattage is dissipated during specific applications. When other types of mountings are employed, the wattage ratings should be properly modified.

103.4.1.2 Bushings

Four types of mount bushings are available:

N ….Standard
L ….Locking
S ….Shaft and Panel Sealing (Standard)
T ….Shaft and Panel Sealing (Locking)

It is recommended that S bushings be used due to longer rotational life.

103.4.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.15.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

***Caution*:** For styles rtr and rjr reduce the max allowable derating curve if the entire element is not used. See 104.1.1.1 and 104.2.1.4.

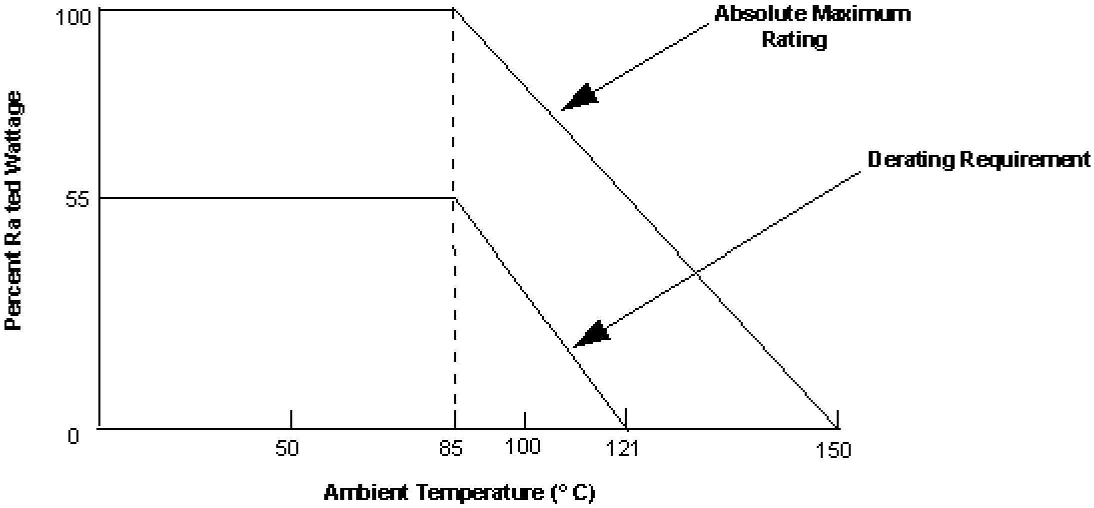


Figure 100.15 -- Derating Requirements for Styles RT, RJ, RTR, RJR

103.5 MIL39002, Resistors, Variable, Wirewound, Semiprecision, (Style RK)

103.5.1 Application Considerations

103.5.1.1 Selection of a Safe Resistor Style

The wattage rating of these resistors is based on operation at 85ºC, mounted on a 4 inch square, 0.050 inch thick, steel panel. This mounting technique should be taken into consideration when wattage is dissipated during specific applications. When using other types of mountings, the power rating must be properly modified.

103.5.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.16.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

Caution: For style RK reduce the max allowable derating curve if the entire element is not used.

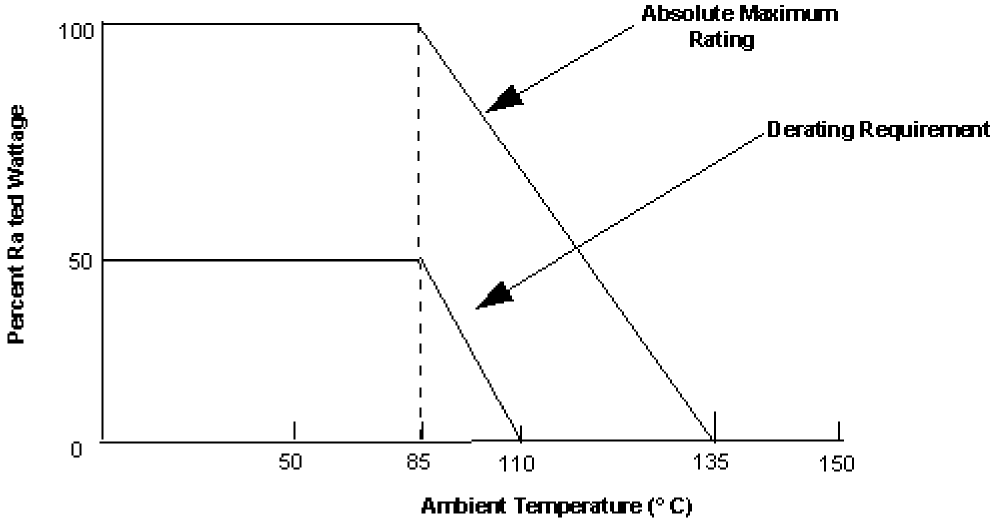


Figure 100.16 -- Derating Requirements for Style RK

103.6 MIL27208, Resistors, Variable, Wirewound (Adjustment Type), (Style RT)

103.6.1 Application Considerations

103.6.1.1 Substitution

Use of MIL-R-39015 style RTR resistors vice MIL-R-27208 style RT, is preferred.

103.6.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.15.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

103.7 MIL22097, Resistors, Variable, Nonwirewound (Adjustment Type) (Style RJ)

103.7.1 Application Considerations

103.7.1.1 Substitution

Use of MIL-R-39035 style RJR resistors vice MIL-R-22097 style RJ, is preferred.

103.7.1.2 Derating Requirements

a. Steady-state conditions -- Under steady-state conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.15.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

103.8 MIL23285, Resistors, Variable, Nonwirewound (Style RVC)

103.8.1 Application Considerations

These resistors are suitable for rheostat or potentiometer applications, where high precision is not required. They are capable of withstanding acceleration, shock, high frequency vibration, and 125ºC operating temperature at rated load. They are most useful in circuitry where high resistance values and lower power dissipation are encountered in volume control, bias, tone voltage, and pulse-width circuit applications.

103.8.1.1 Selection of Safe Resistors

The wattage ratings of these resistors are based on operation at 125ºC mounted on a 16-gage steel plate, 4 inch square. This mounting technique should be taken into consideration when wattage is dissipated during specific applications. When using other types of mountings, the power ratings should be properly modified.

103.8.1.2 Linear and Nonlinear Tapers

As shown in Figure 100.17, Taper A is a linear resistance taper, which is one having a constant change of resistance with angular rotation, while Taper C is a nonlinear resistance taper.

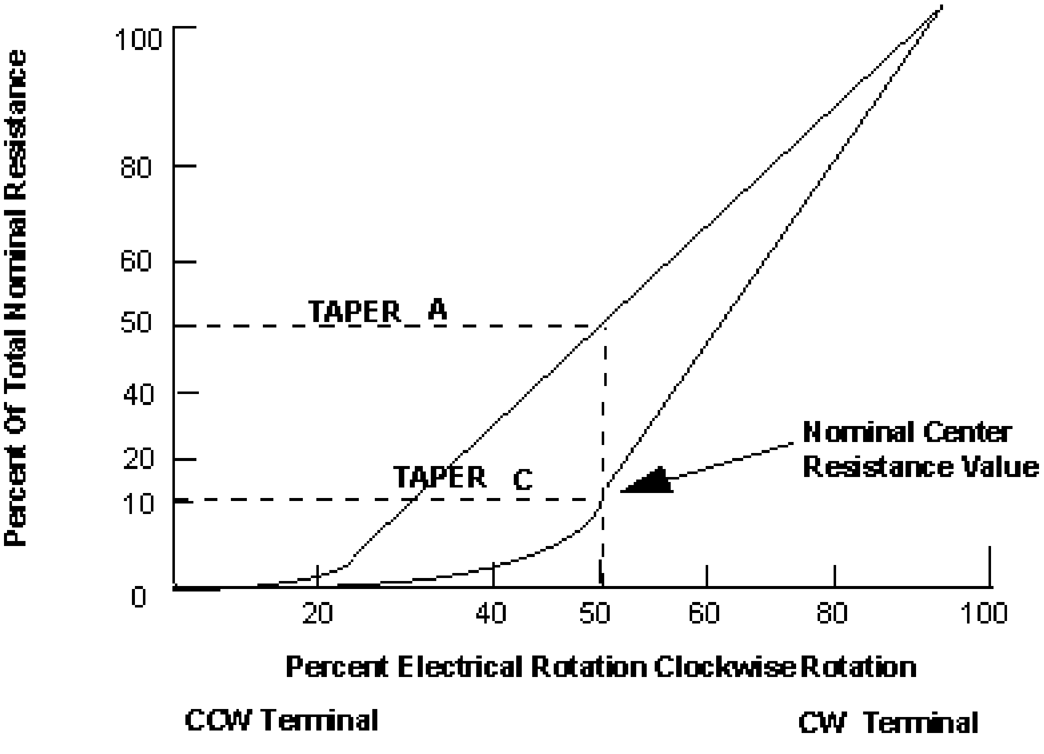


Figure 100.17 -- Linear and Nonlinear Tapers for RVC Resistors

103.8.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.18.

b. Pulse circuit application -- This resistor is suitable for pulse circuits in which applied voltage is limited to values that will not cause the derated power dissipation to be exceeded.

Caution: For style RV reduce the max allowable derating curve if the entire element is not used.

Note: For potentiometer applications, it is necessary to consider both load and bleeder current in determining resistor power dissipation.

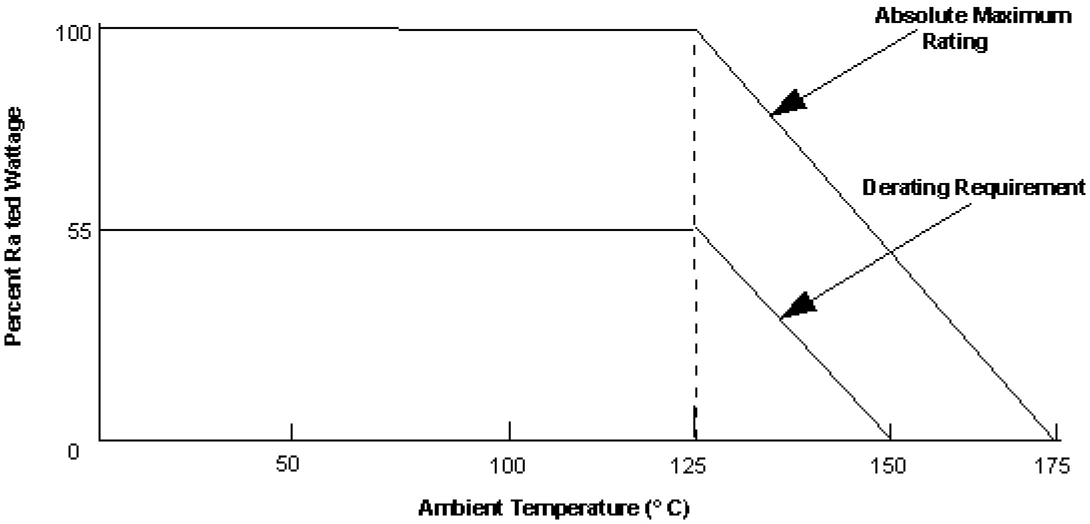


Figure 100.18 -- Derating Requirements for Style RVC06

103.9 MIL39023, Resistors, Variable, Nonwirewound, Precision, (Style RQ)

103.9.1 Application Considerations

103.9.1.1 Output

The output of these resistors (in terms of percent of applied voltage) is linear with respect to the angular position of the operating shaft.

103.9.1.2 Temperature Characteristics

An average resistance change of ± 10 percent due to temperature cycling is common.

103.9.1.3 Selection of Safe Resistors

The wattage rating of these resistors is based on operation at 70ºC, mounted on a 4 inch square, 0.25 inch thick alloy aluminum panel. This mounting technique should be taken into consideration when wattage is dissipated during specific applications. When using other types of mountings, the wattage ratings should be properly modified.

103.9.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.19.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

***Caution*:** For style RQ reduce the max allowable derating curve if the entire element is not used.

Figure 100.19 -- Derating Requirements for Styles RQ100, 110, 150, 160, 200, 210, 300 and RQ090

104 Resistors, Variable, Established Reliability

104.1 MIL39015, Resistors, Variable, Wirewound (Lead Screw Actuated), Established Reliability (Style RTR)

104.1.1 Application Considerations

104.1.1.1 Selection of a Safe Resistor Style

The wattage ratings of these resistors are based on operation at 85ºC when mounted on a 1/16 inch thick, glass base, epoxy laminate. Therefore, the heat sink effect as provided by steel test plates in other specifications is not present. The wattage rating is applicable when the entire resistance element is imbedded and operational in the circuit. When only a portion is engaged, the wattage is reduced directly in the same proportion as the resistance.

104.1.1.2 Mounting

Resistors with terminal Type L should not be mounted by their flexible wire leads. Mounting hardware should be used. Printed-circuit types are frequently terminal mounted, although brackets may be necessary for high-shock and vibration environments.

104.1.1.3 Environmental Conditions

Special care should be taken when using these resistors in highly humid conditions, to avoid turn-to-turn shorts. It is advisable to avoid the use of these resistors in high humidity environments.

104.1.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.15.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

104.1.3 Quality Level

Only ER level “R” or higher shall be used.

104.2 MIL39035, Resistors, Variable, Nonwirewound (Lead-Screw Actuated), Established Reliability (Style RJR)

104.2.1 Application Considerations

104.2.1.1 Tolerance

These resistors have a resistance tolerance of + 10 percent. Regardless of the purchase tolerance, the design should be such as to tolerate a + 10 percent shift in resistance value to assure long life reliability in military applications.

104.2.1.2 Resolution

The resolution of style RJR resistors is very high (essentially infinite).

104.2.1.3 Noise

The noise level is not controlled by the resistor specification but it is normally found to be relatively low.

104.2.1.4 Selection of Safe Resistors

The wattage ratings of these resistors are based on operation at 85ºC when mounted on a 1/16 inch thick, glass base, epoxy laminate. Therefore, the heat sink effect as provided by steel test plates in other specifications is not present. The wattage rating is applicable when the entire resistance element is imbedded and operational in the circuit. When only a portion is engaged, the wattage is reduced directly in the same proportion as the resistance.

104.2.1.5 Secondary Insulation

Where voltages higher than 250 volts rms are present between the resistor circuit and grounded surface on which the resistor is mounted, secondary insulation should be provided between the resistor and the mounting or between the mounting and ground.

104.2.1.6 Resistor Mounting

Resistors with terminal Type L should not be mounted by their flexible wire leads. Mounting hardware should be used. Printed-circuit types are frequently terminal mounted, although brackets may be necessary for high-shock and vibration environments.

104.2.1.7 Variation

Contact resistance variation normally will not exceed 3 percent or 20 ohms for characteristic C, and 3 percent or 3 ohms for characteristics F and H, whichever is greater.

104.2.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.15.

b. Pulse circuit application -- This resistor is not suitable for pulse circuits.

104.2.3 Quality Level

Only ER level “R” or higher shall be used.

105 Special Resistors

105.1 MIL83401, Resistor Networks, Fixed, Film, (Style RZ)

105.1.1 Application Considerations

The RZ style resistors are in a resistor network configuration having a film resistance element and in a DIP or flat pack configuration. These resistors are stable with respect to time, temperature and humidity and are capable of full load operation at an ambient temperature up to 70ºC after which they are derated to zero power at 125ºC.

105.1.1.1 Use

These resistors are designed for use in critical circuitry where stability, long life, reliable operation and accuracy are of prime importance. They are particularly desirable for use where miniaturization is important. They are also useful where a number of resistors of the same resistance values are required in the circuit.

105.1.1.2 Operating Frequency

When used in high frequency circuits (200 MHz and above), the effective resistance will be reduced as a result of shunt capacitance between resistance elements and connecting circuitry. The high frequency characteristics of these networks are not controlled by specification.

105.1.1.3 Noise

Noise output is not controlled by specification, but is typically very low for these resistors.

105.1.1.4 Resistance Tolerance

Operation of these resistor networks under variable ambient conditions could cause permanent or temporary changes in resistance sufficient to exceed their initial tolerances. In particular, operation at extremely high or low ambient temperatures cause significant temporary changes in resistance. Care should be taken to assure that the circuit design will tolerate these changes.

105.1.1.5 Mounting

Under severe shock or vibration conditions (or a combination of both), the resistor network should be restrained from movement relative to the mounting base. If clamps are used, certain electrical characteristics can be altered. Heat dissipating qualities will be enhanced or degraded depending on whether clamping material is a good or poor conductor of heat. This phenomenon should be given due consideration.

105.1.1.6 Electrostatic Susceptibility

Most film resistors are found to be susceptible to electrostatic discharge (ESD) induced damage. Handling, transporting, and production procedures should take precautions to avoid ESD problems.

105.1.2 Derating Requirements

a. Steady-state conditions -- Under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.10.

b. Pulse circuit application -- When using these resistors under pulse conditions, the following conditions shall be met:

  (1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.10.

  (2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-83401).

106 Thermistors

106.1 General Information

A thermistor is an intentionally thermally sensitive element whose primary function is to alter its electrical resistance in response to changes in body temperature. MIL-T-23648 is the key overall specification for thermistor selection. Supplement 1B to this specification provides detail specifications for various configurations.

Actual thermistor resistance is a function of its absolute temperature. The relationship between thermistor resistance and its temperature is often expressed as:

$$\frac{R(T)}{R(T_0)} \quad = \quad \begin{array}{c} \text{-ß} \; [1 \text{ -- } 1] \\ [\text{—}] \\ \in \; [TT_0] \end{array}$$

where: R(T) = Thermistor resistance at some temperature T(ºK)
R(T_0) = Thermistor resistance at an initial measurement temperature T (ºK)
ß = Thermistor material constant

The dissipation constant, usually expressed in mW/ºC represents the amount of power required to induce a temperature rise of 1ºC.

The time constant is usually expressed in seconds and is defined as the time required for a thermistor to change 63.2 percent of the total difference between initial and final body temperature when subject to a step function change in temperature under zero-power conditions.

Thermistors are mixtures of metal oxides which are fused at high temperature to a sintered ceramic-like semiconductor material. Major classifications are in terms of negative or positive temperature coefficients of resistance. These large temperature coefficients are responsible for the resistance ratio characteristics (defined as measured values at 25ºC versus 125ºC (i.e., 0.5, 19.8, 29.4). Negative temperature coefficient thermistors display large decreases of resistance as a function of increasing temperature and are usually available in resistance values from 1to 1M. Positive temperature coefficient units can display very large increases in resistance over temperature ranges from below 0ºC to 200ºC. Below the Curie temperature (i.e.) that temperature which separates magnetic and paramagnetic properties, the thermistor temperature coefficient is slightly negative. Various packaging schemes are available and include chips, epoxy dipped, molded, T0-5 can, and glass encapsulation.

Most thermistors are available in either disc, bead or rod construction. Discs are constructed by high pressure forming of oxide-binder mixtures into flat or disc shapes. These are electrically characterized by low resistance values, short time-constants (resistance variance induced by self-heating effects), and high power dissipation. The bead forms are constructed by viscous droplet ellipsoids onto wire leads, then subject to high temperature sintering. These are often glass coated or mounted in bulbs. Because of low thermal mass, they are characterized by short time-constants. The rod forms are often useful as temperature probes and are constructed by die extrusions into relatively long cylinders. They are characterized by high resistance, longer time-constants, with relatively moderate power dissipation.

Some examples:

a. Many circuit configurations, either active or passive, contain components whose temperature coefficients can degrade the thermal stability of the network. Thermistors can be used in such circuits to provide a means for temperature compensation.

b. Large temperature coefficients of resistance are useful for measurement of temperature, providing power dissipation levels are kept low enough to minimize self-heating effects. Precise temperature measurement and monitoring can be achieved using high-resistance units in resistance bridge networks. Sensitivity levels of 0.0005ºC can be attained in such applications; lead resistance compensation is not required. Remote temperature measurement requirements can be met using bead thermistors in resistance bridges.

c. Power measurements are made using thermistor resistance-power characteristics, particularly in microwave operating regions. The technique uses a bead thermistor inserted in a waveguide network biased such that bead and cavity impedances are matched. During RF power application the thermistor is heated by absorbed power. If bias current is kept adjusted to maintain thermistor operating temperature, then the required changes in bias power are equal to RF power absorbed.

d. Other applications include time-delay networks for relays and in-rush current protection, voltage regulation, communication circuit volume limiters and wave shaping circuits in signal transmission networks.

106.2 Application Considerations

106.2.1 Reliability

In those applications in which negative temperature coefficient thermistors are used, care must be taken to avoid the occurrence of thermal runaway. This occurs during certain applications in which the self-heating effect due to current flow causes a drop in thermistor resistance, resulting in still more current-induced self-heating, and the process continues until the device burns out. To prevent such occurrences, the specified maximum operating temperature of the device must not be exceeded. Although thermal runaway may not occur in the event the maximum operating temperature is exceeded, a permanent resistance change can occur. Use of current limiting resistors can help to prevent thermal runaway. Effects of mechanical stress due to vibration, shock, or acceleration are minimized by proper mounting or encapsulation.

106.2.2 Derating

106.2.2.1 The derating stress parameters are rated power and ***ambient*** temperature.

a. Steady-state conditions -- Derate in accordance with the maximum allowable derating curve for power as shown in Figure 100.20.

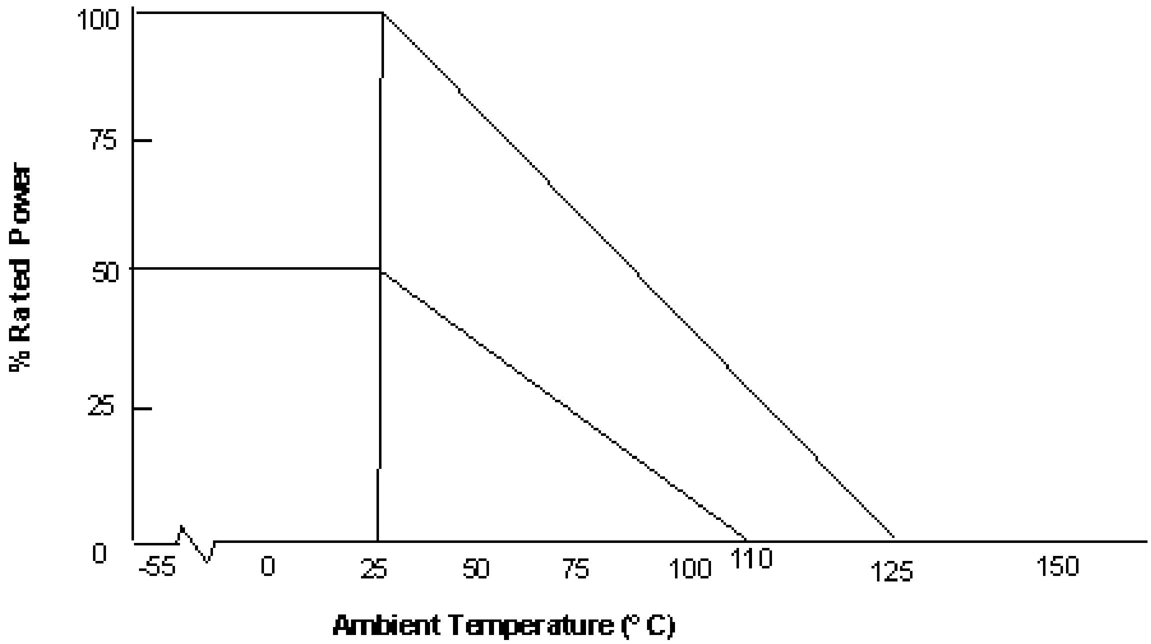


Figure 100.20 -- Thermistor Power Derating

Next Section

Previous Section

Section 200 -- Capacitors

200 Capacitors, General

200.1 General Information

Standard capacitors are specified in MIL-STD-198. This standard presents detailed data for use in the design of military equipment and should be used to the greatest extent possible for capacitor selection. Data is presented on terminology, capacitor selection, environmental effects on characteristics and life, applications, application data, failure rates and aging curves. The following information has been excerpted from MIL-STD-198.

Capacitors can be broadly categorized into the following types according to the dielectric material used:

a. Ceramic dielectric

b. Glass dielectric

c. Aluminum dielectric

d. Solid tantalum dielectric

e. Non-solid tantalum dielectric

f. Mica dielectric

g. Paper, paper-plastic or plastic dielectric

h. Film; paper-plastic or plastic dielectric

200.2 Application Considerations

200.2.1 Dielectric Versus Volume

In electrolytic capacitors, the dielectric is an almost negligible part of the volume of the capacitor. In other capacitors, such as mica, plastic, ceramic, and glass dielectrics, the dielectric comprises nearly the entire volume of the capacitor element. Theoretically, then, for all capacitors except electrolytic, where almost the entire volume of the unit is an active dielectric, the volume is directly proportional to CV^2 where C is the capacitance and V is the maximum voltage rating). The proportionality constant depends on the dielectric constant of the material, its dielectric strength, and the life expected of the capacitors. For the electrolytic types, the volume has been found empirically to vary more nearly with CV than CV^2.

200.2.2 Commercial Capacitors

Conclusions can be made concerning the reliability expected from commercial capacitors by comparing them with similar military capacitors of the same dielectric and capacitance. The commercial unit is a short-life, less reliable part. Therefore, only military capacitors with an ER quality level "R" or higher **may** be used without approval of the procuring activity.

200.2.3 Voltage Rating and Life

Since the catastrophic failure of capacitors is usually caused by dielectric failure, voltage ratings of non-electrolytic capacitors are based on a given life expectancy at a maximum ambient temperature and voltage stress. Dielectric failure is typically a chemical effect, and for well-sealed units, where atmospheric contamination of the dielectric does not contribute, is a function of time, temperature, and voltage. The time-temperature relationship affects the chemical activity or rate of degradation; that is degradation proceeds at a doubled rate for each 10ºC rise in temperature (e.g., a capacitor operating at 100ºC will have half the life of a similar one operating at 90ºC). Extensive studies have been made of certain organic dielectrics where it has been found that the deterioration is proportional to V^5 (fifth power of the voltage). For example, a capacitor operating at 20 Volts will last 32 times as long as a similar one operating at 40 Volts. The 10ºC rule is applicable only over a temperature range where no significant changes of state occur to affect the dielectric. That is, no freezing, melting, boiling, condensing, loss or gain of water, crystallization or other change in stable crystal structure. The V^5 rule is also subject to modification by consideration that the dielectric **may** puncture suddenly if some particular voltage stress is exceeded, and that there are other electric fields (notably around the edges of the dielectric extending beyond the conducting plates) where breakdown can occur without failure of the principal dielectric.

200.2.4 Reliability

Figure 200.1 presents a sample comparison of predicted part operating failure rates for Established Reliability (ER) capacitors. The part operating failure rates shown are developed from the part operating failure rate models from MIL-HDBK-217. The part operating failure rates are representative of a given military environmental condition and stress level and are not necessarily in the same proportion for other environments or operating conditions. **More complete, extensive, and exact data are provided by MIL-HDBK-217.**

200.2.5 Operating Frequency

All capacitors have some operating frequency limitations due to the nature of the dielectric and other construction features. Figure 200.2 shows the operating frequency ranges for common types of capacitors. The frequency range for electrolytics is not readily described in this manner, because the effective capacitance of these type parts involves a complex relationship of voltage rating, case size, nominal capacitance value, and operating frequency. Capacitor operation with alternating currents and under pulse or energy storage conditions involves consideration of a number of factors in addition to the voltage rating. The major factor in selecting capacitors for alternating current operation and energy storage and pulse applications is heat dissipation. Heat is generated as a result of the Equivalent Series Resistance (ESR) and dielectric losses, and, to a lesser extent, by losses in the attachment of the lead wires to the capacitor elements.

Capacitors for these applications must have the construction, the case size, and the losses, particularly the ESR, carefully controlled by specification or by special screening to assure reliable performance in the operating circuit.

<u>Caution</u>: These values are given for illustrating purposes only and should not be considered absolute. The exact failure rate depends on the maximum temperature rating and capacitance value.

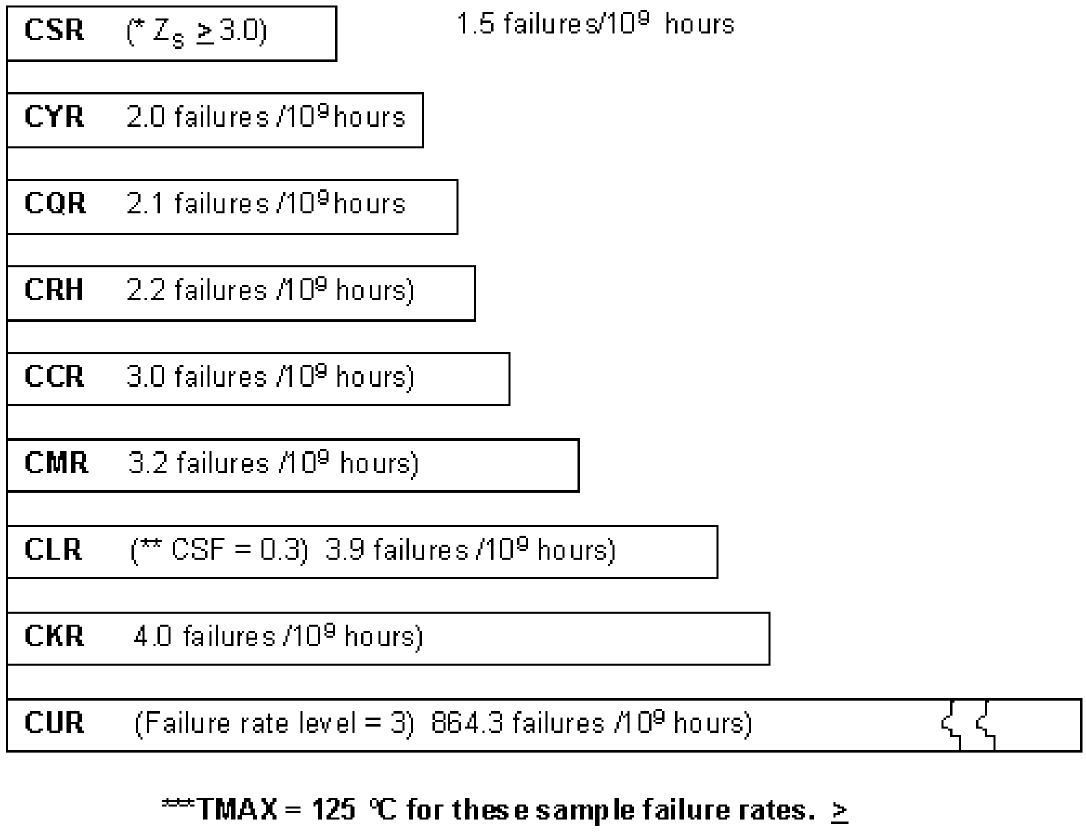


Figure 200.1 -- Representative Part Operating Failure Rates for Some Established Reliability Capacitors Establishment of Part Operating Failure Rates:

1. MIL-HDBK-217 part operating failure rate models
2. Stress level (S) = 0.4
3. Ambient temperature (T_A) = 70ºC
4. Naval Sheltered (N_S) environment
5. Failure rate level = P
6. Capacitance factor = 1.0

* Z_S = Series resistance adjustment factor for this style capacitor in circuit applications; denoted by π_{SR} by MIL-HDBK-217 (Ohms per applied Volt)

** CSF = Construction factor accounts for hermetic/non-hermetic seal effects with CL and CLR capacitors; denoted by $_{C}$ by MIL-HDBK-217

*** T_{MAX} = Maximum operating temperature (ºC)

200.2.6 Capacitor Selection Factors

Factors to be considered in capacitor selection are:

- Capacitance
- Temperature
- Humidity
- Barometric pressure
- Applied voltage
  - Alternating/ripple current
  - Frequency
  - Dissipation factor
  - Equivalent series resistance
  - Reverse voltage levels
- Capacitance voltage product per unit volume

200.3 Capacitor Part Types

General information and derating requirements for capacitors are provided herein.

201 Capacitors, Ceramic Dielectric

201.1 Application Considerations

201.1.1 Temperature Compensation Application

These capacitors are primarily used for compensation of reactive changes caused by temperature variations in other circuit parts and in precision type circuits where their characteristics are suitable. Ceramic capacitors are substantially smaller than paper or mica units of the same capacitance and voltage rating. They have tighter capacitance tolerances than mica or paper capacitors and their lead construction is highly suitable for printed-circuit use.

These units can be used to compensate frequency drift in radio frequency **(RF)**, oscillator, and intermediate frequency (IF) circuits caused by temperature variations. In IF stages where the frequency variation is uniform, satisfactory operation can be obtained by designing the temperature- compensating capacitor into the oscillator circuit. RF circuit reactive changes caused by temperature variations cannot be compensated for in the oscillator circuit; in these cases where most critical tuning accuracy is required, it is necessary that compensating capacitors be inserted directly into each circuit.

In RF circuits tuned by a variable capacitor, a shunt compensating capacitor of low value and high compensating characteristics can be used. In slug-tuned circuits, the total capacitance required can be provided by using a compensating capacitor having the desired temperature coefficient. In oscillator circuits, more linear tuning can be obtained by selecting capacitors with the proper temperature coefficients in both the series and the shunt capacitances of the tank circuit.

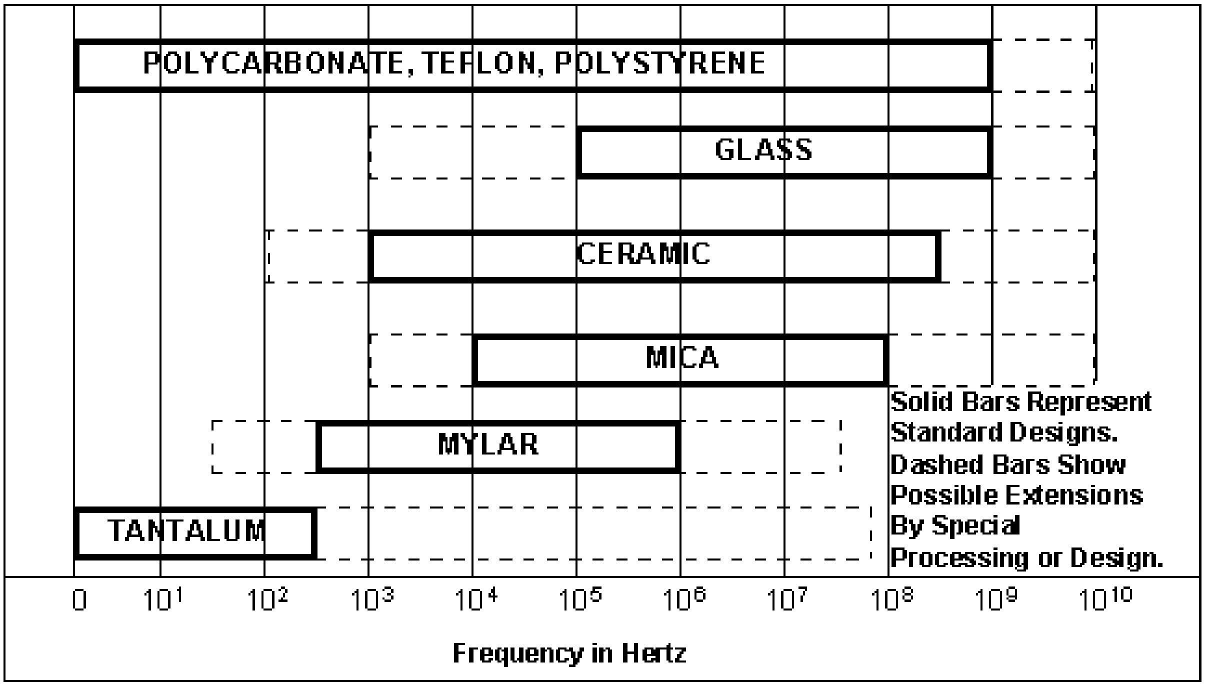


Figure 200.2 -- Operating Frequency Limits of Capacitors

- Vibration
- Current
- Life
- Stability
- Retrace
- Size
- Volume
- Mounting method
- Cost

201.1.2 Insulation Resistance

The high insulation resistance of these capacitors is well suited to coupling applications between plate and grid circuits of electron tubes. Extremely low leakage and small physical size make them suitable for transistor circuit design. They are also used in filter and by-pass circuits.

201.1.3 Temperature Compensation of Coils

The temperature-time curve of the selected capacitor should be the exact opposite of the temperature-time curve of the coil or other part being compensated. Combinations of different capacitance values and temperature coefficients can give more precise compensation than can be obtained from a single capacitor. Full consideration should be given to the physical placement of compensating capacitors. Locations near hot operating parts could affect the designed-in circuit temperature compensation.

201.1.4 Capacitance to Size Ratio

These capacitors have the largest capacitance to size ratios of all high resistance dielectric capacitors.

201.1.5 Capacitance Variation

Capacitance changes with variation in voltage, frequency, age and temperature should be determined from the detailed specifications.

201.1.6 Humid Operating Conditions

Ceramic materials are non-hygroscopic, effectively impermeable and have practically no moisture absorption even after considerable exposure to highly humid conditions. These capacitors are intended to operate, through their full temperature range, at relative humidities up to 95 percent. However, the terminal materials under high moisture conditions can be subject to ionic migration which can cause capacitor failure.

201.1.7 AC Operation

When AC operation is required, the peak ac voltage plus any DC bias shall not exceed the derated values established by the derating requirements.

201.1.8 Mounting

These capacitors are used to compensate circuit performance for temperature variations. Therefore, they should be mounted in close proximity to the part (or parts) they are intended to compensate, and isolated from parts that dissipate local heat. Otherwise thermal gradients will defeat the designed-in compensation capability.

201.1.9 Frequency Considerations

Since the ceramic dielectric used is frequency sensitive, both capacitance and capacitance change with temperature will be different at different measuring frequencies. For extremely accurate compensation, the compensation characteristics should be measured at the proposed operating frequency.

201.1.10 Derating Factors

Due to the low capacitive reactance, at high frequencies and with high capacitances, the continuous duty current will usually be reached at a voltage below the maximum rated voltage.

Similarly, due to the high capacitive reactance at low frequencies and with low capacitances, the maximum voltage will often be reached before the rated current. Necessary care should be taken to ensure that neither current nor voltage exceed the derated value established by the derating requirements specified for each capacitor type.

201.2 MIL--C--20, Capacitors, Fixed, Ceramic Dielectric (Temperature Compensating), Established Reliability, (Style CCR)

201.2.1 Application Considerations

201.2.1.1 Capacitance Tolerance

These capacitors come in tolerances of +0.1 pf, + .25 pf, + .5 pf, +1 percent, +2 percent, +5 percent, and +10 percent. However, regardless of the purchase tolerance, the design should tolerate a +1 percent absolute change in capacitance value to assure long life reliability in military applications. The temperature characteristics, however, are expected to remain virtually unchanged throughout the life of the capacitor.

201.2.1.2 Dielectric Strength

Where the capacitor body will normally contact parts with a potential difference of more than 750 volts, supplementary insulation shall be used.

201.2.1.3 Temperature Coefficient

These capacitors exhibit zero and negative temperature coefficients which can be used for temperature compensation.

201.2.1.4 Operating Frequency

These capacitors are suitable for operating frequencies ranging from 1 kHz to 300 MHz.

201.2.2 Derating Requirements for Styles CCR05, 06, 07, 08, 75, 76, 77, 78

The voltage shall be derated according to the derating curve shown in Figure 200.3. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.3.

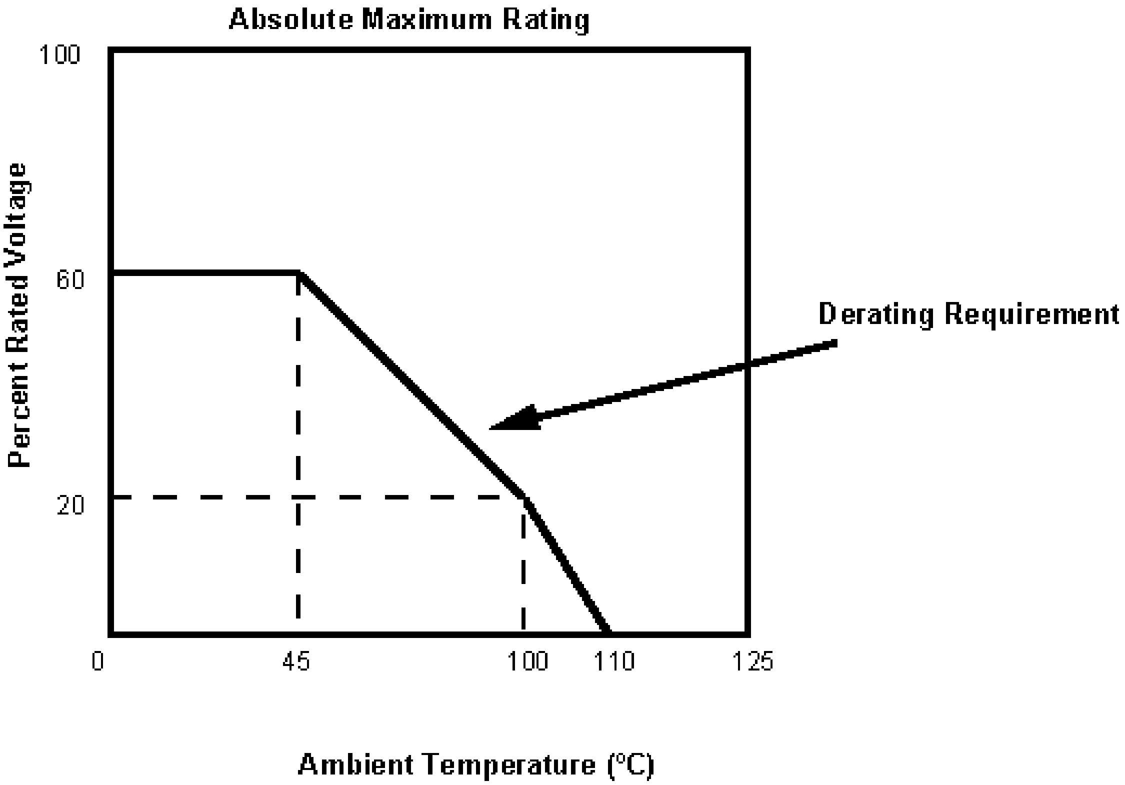


Figure 200.3 -- Derating Requirements for Styles CCR05, 06, 07, 08, 75, 76, 77, 78

201.2.3 Quality Level

Only ER level "R" or higher shall be used.

201.3 MIL--C--39014, Capacitors, Fixed, Ceramic (General Purpose), Established Reliability, (Style CKR)

201.3.1 Application Considerations

These capacitors are primarily designed for use where a small physical size with comparatively large electrical capacitance and high insulation resistance are required. Because of the cumulative effects of temperature, applied voltage, and aging, these capacitors are recommended for use only where broad variations in capacitance value can be tolerated. The dielectric constant usually decreases with increases in age, frequency, and temperature.

201.3.1.1 Humid Operating Conditions

Ceramic dielectric materials are nonhygroscopic, effectively impermeable, and have practically no moisture absorption even after considerable exposure to humid conditions. Thus, these units are intended to operate, through their full temperature range, at relative humidities up to 95 percent.

201.3.1.2 Soldering

Care should be used in soldering the leads. Excessive heat may damage the encapsulation and weaken the electrode to terminal lead contact. sudden changes in temperature, such as those experienced in soldering, can crack the encapsulation or the ceramic dielectric. Leads should not be bent close to the case nor should any strain be imposed on the capacitor body to avoid fracturing the encapsulation or ceramic dielectric.

201.3.1.3 Capacitance Tolerance

These capacitors are available with initial tolerances of +10 percent or +20 percent. However, regardless of the purchase tolerance, the design should tolerate a +20 percent change in capacitance value to assure long life reliability in military applications.

201.3.1.4 Operating Frequency

These capacitors are suitable for use as by-pass, filter, and non-critical coupling elements in high frequency circuits, with the typical operating frequency ranging from 1 kHz to 300 MHz.

201.3.2 Derating Requirements for Styles CKR05, 06, 11, 12, 14, 15

The voltage shall be derated according to the derating curve shown in Figure 200.4. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.4. These derating requirements only apply to those capacitors having a rated temperature range of -55ºC to +125ºC.

Style	**T_D (ºC)**	**T_{MAX}(ºC)**
	120	150
CKR	110	125
	70	85

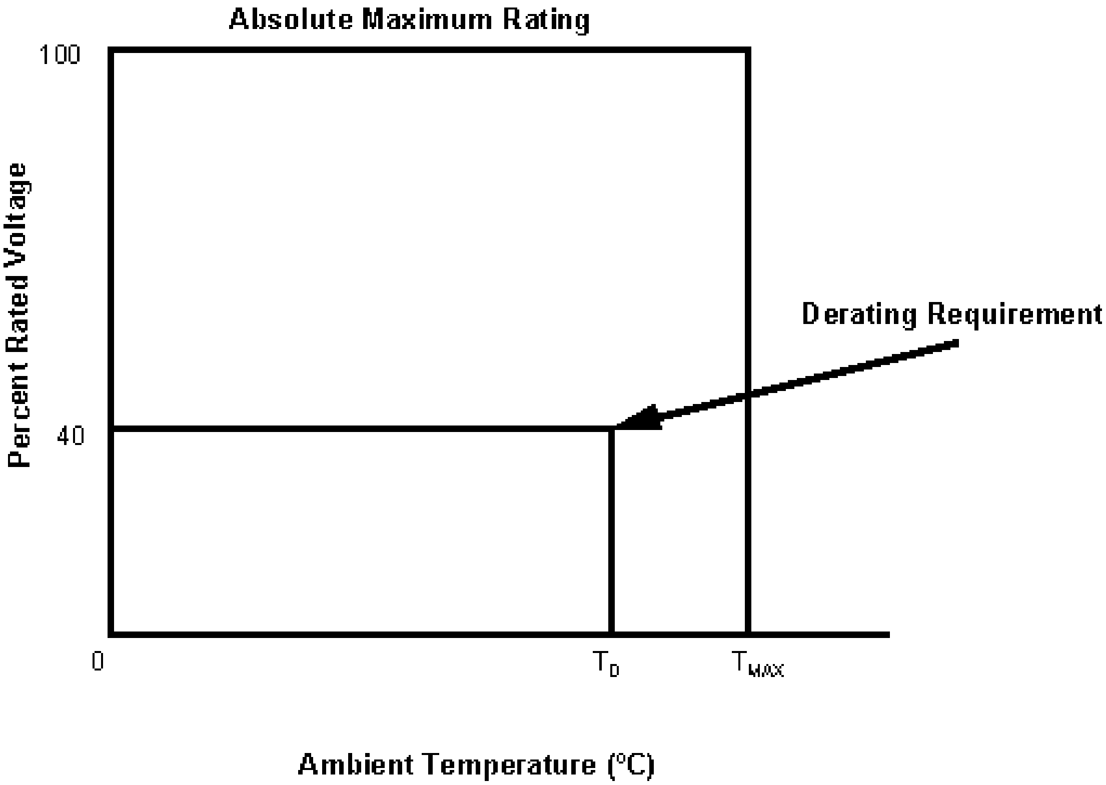


Figure 200.4 -- Derating Requirements for Styles CKR05, 06, 11, 12, 14, and 15

201.3.3 Quality Level

Only ER level "R" or higher shall be used.

201.4 MIL--C--81, Capacitors, Variable, Ceramic Dielectric, (Style CV)

201.4.1 Application Considerations

These capacitors are small-sized trimmer capacitors. They can be used for fine tuning, trimming, and coupling in such circuits as intermediate frequency, radio frequency, oscillator, phase shifter, and discriminator stages.

201.4.1.1 Temperature-Capacitance Characteristics

Changes in nominal capacitance from the values measured at +25ºC may vary from -4.5 percent to +14 percent at -55ºC or -10 percent to +2 percent at +85ºC when measurements are made: (1) after the capacitors have reached thermal stability; (2) at a frequency range of 0.1 to 0.2 MHz and with the capacitor adjusted to 80 to 90 percent of maximum capacity.

201.4.1.2 Drift with Age

Capacitance change as a result of aging is less than 0.5 pf.

201.4.1.3 Mounting

These capacitors may be mounted close to a metal panel with little increase in capacitance. To avoid cracking or chipping of the ceramic mounting base, a resilient mounting (or mounting surface spacer) should be used.

201.4.1.4 Stability

Even though these capacitors are relatively stable against shock and vibration, air trimmers, due to their low mass, should be used where a higher order of stability is required.

201.4.1.5 Temperature Sensitivity

These capacitors should not be designed into circuits as temperature compensating units since the temperature sensitivity is non-linear over the capacitance range and varies greatly between units.

201.4.2 Derating Requirements for Styles CV11, 21, and 31

The voltage shall be derated according to the derating curve shown in Figure 200.5. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.5.

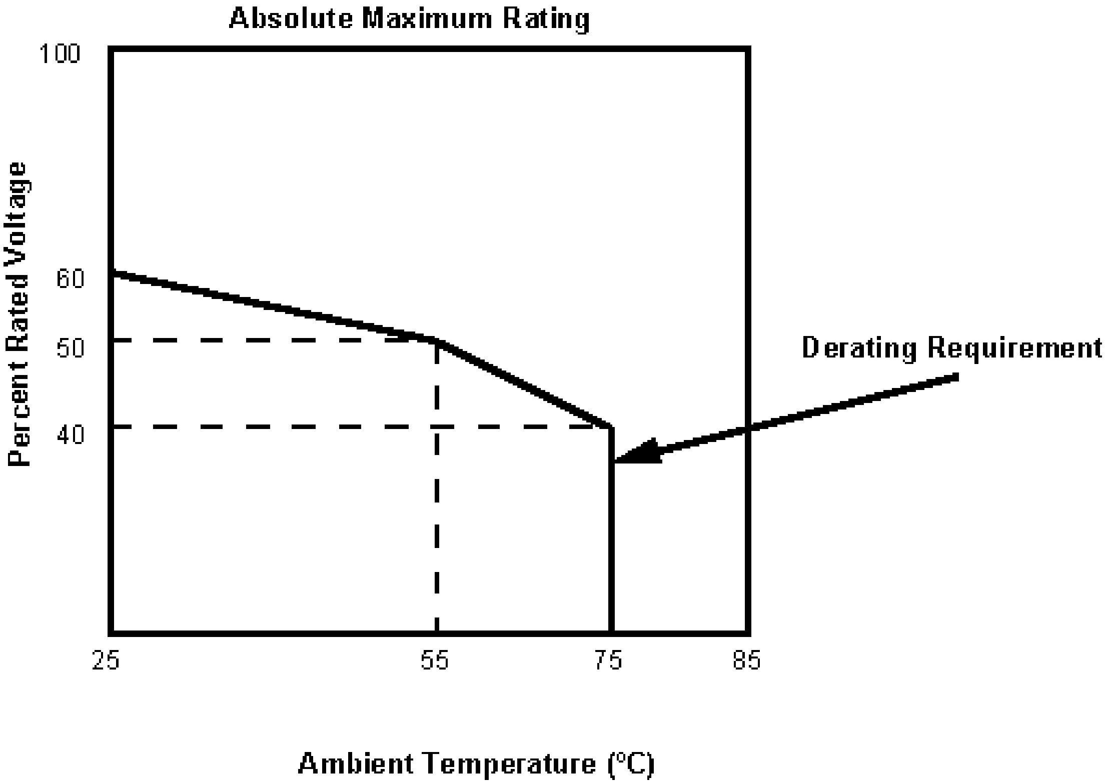


Figure 200.5 -- Derating Requirements for Styles CV11, 21, 31, and CG60

202 Capacitors, Gas or Vacuum Dielectric

202.1 MIL-C--23183, Capacitors, Variable, Gas or Vacuum Dielectric, Ceramic Envelope, (Style CG)

202.1.1 Application Considerations

202.1.1.1Voltage Rating

The voltage rating is the 60 Hz test voltage, at maximum capacity. This is the absolute maximum voltage the unit can withstand before breakdown occurs. The breakdown voltage is greater at capacities less than maximum, becoming as much as 300 percent greater at minimum capacity for lower voltage units. The breakdown voltage at radio frequencies is the same as for low frequencies up to about 2.5 MHz, and becomes about 10 percent lower at 30 MHz. The continuous duty operating voltage is lower for higher frequencies. The continuous RF rating of a vacuum capacitor is arbitrarily defined as that voltage and current that will raise the temperature to a steady 85ºC without cooling apparatus. This rating can be increased by additional cooling such as blowers, heat sinks, or water cooling.

202.1.1.2 Use of Large Conductors

When using large conductors for better heat dissipation, care should be taken to avoid excessive mechanical loading by these conductors.

202.1.2 Derating Requirements for Style CG60

The voltage shall be derated according to the derating curve shown in Figure 200.5. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.5.

203 Capacitors, Glass Dielectric

203.1 MIL-C-14409, Capacitors, Variable (Piston Type, Tubular Trimmer), (Style PC)

203.1.1 Application Considerations

These capacitors are small-sized, sealed, tubular trimmer, variable capacitors designed for fine tuning adjustments. They are normally used for trimming and coupling in such circuits as intermediate frequency, radio frequency, oscillator, phase shifter, and discriminator stages.

203.1.1.1 Stability

Because of their low mass, these capacitors are relatively stable against shock and vibration.

203.1.1.2 Linearity and Backlash

The capacitance change is linear with respect to rotation within +10 percent. Backlash is virtually non-existent except on Styles PC39 and PC43 which can have a backlash of 2 percent.

203.1.1.3 Torque

For styles PC25 and PC26 capacitors, the driving torque is between 0.5 and 6.0 ounce-inches throughout the temperature range (-55ºC to +125ºC); and 1 to 10 ounce-inches at all other temperatures within the operating temperature range.

203.1.1.4 AC Operation

When AC operation is required, the peak ac voltage plus any DC bias should not exceed the value established by the derating requirements.

203.1.2 Derating Requirements for Styles PC25, 26, 39, 43, 48, 52

The voltage shall be derated according to the derating curve shown in Figure 200.6. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.6.

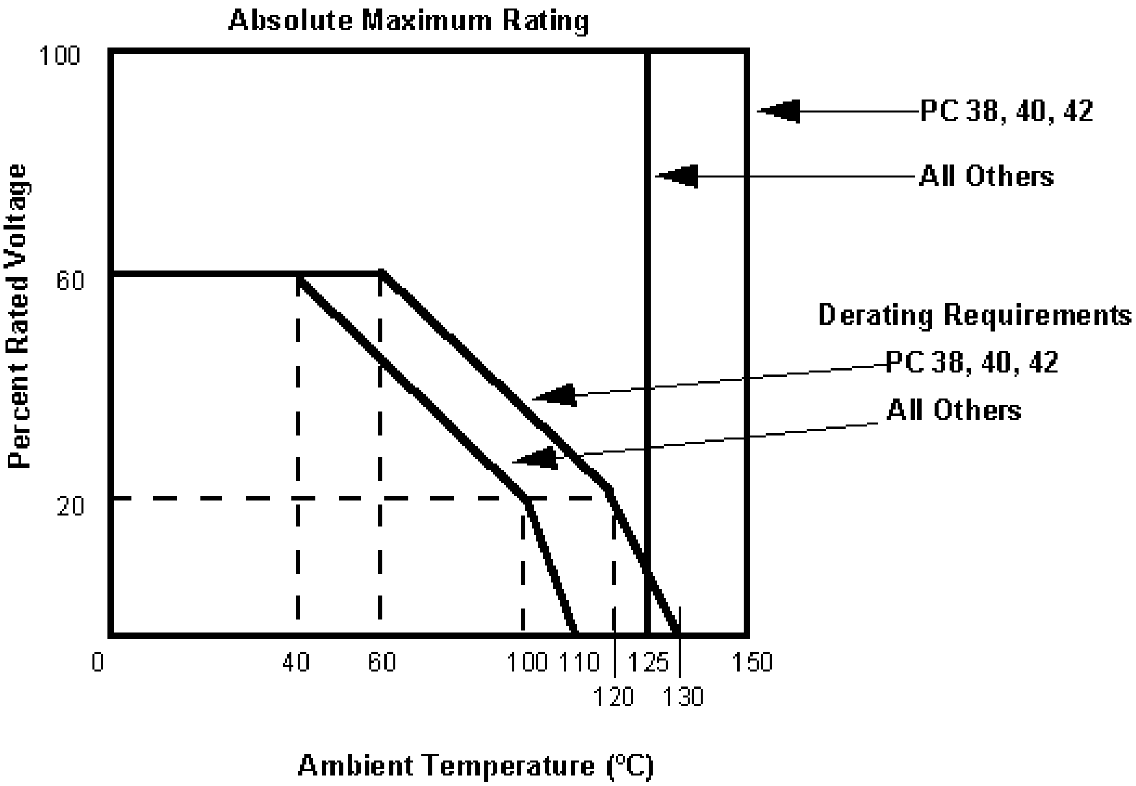


Figure 200.6 -- Derating Requirements for Styles PC25, 26, 38, 39, 40, 42, 43, 48, and 52

203.1.3 Derating Requirements for Styles PC38, 40, and 42

The voltage shall be derated according to the derating curve shown in Figure 200.6. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.6.

203.1.4 Construction

Styles PC25 and PC26 capacitors are constructed with a series of concentric circular metal bands forming plates which interleave. The capacitance is varied by adjustment of the relative depth of engagement of the metal bands. All other style capacitors are constructed of glass or quartz dielectric cylinders and metal tuning pistons. A portion of the cylinder is plated with metal to form the stator. The metal piston, controlled by a tuning screw, acts as the rotor. Overlap of the stator and rotor determines the capacitance. The self-contained piston within the dielectric cylinder functions as a low inductance coaxial assembly.

203.2 MIL-C-23269, Capacitors, Fixed, Glass Dielectric, Established Reliability, (Style CYR)

203.2.1 Application Considerations

These capacitors are intended for use where high insulation resistance, low dielectric absorption and fixed temperature coefficients are important circuit parameters. They are particularly useful in high frequency applications. They are capable of withstanding environmental conditions of shock, vibration, acceleration, extreme moisture, vacuum, extended life of 30,000 hours or greater, and high operating temperature experienced in missile borne and space electronic equipment.

203.2.1.1 Capacitance Tolerance

These capacitors come with tolerances of ±0.25 pf, ±1 percent, ±2 percent, and ±5 percent. However, regardless of purchase tolerance, the design should be able to tolerate a ±1 percent change in capacitance value to assure long life reliability in military applications.

203.2.1.2 Operating Frequency

These capacitors perform very well at high frequencies up to 500 MHz with a typical operating frequency of 100 kHz to 1 GHz.

203.2.1.3 Temperature Coefficient and Capacitance Drift

These capacitors are available with three temperature coefficients. For the axial lead capacitors, the temperature coefficient is 140 + 25 PPM/ºC (for style CYR41). For the axial-radial lead capacitors, the temperature coefficient is 105 + 25 PPM/ºC. The capacitance drift is +0.1 percent or 0.1 pf, whichever is greater, for all capacitors.

203.2.1.4 AC Operation

When AC operation is required, the peak ac voltage plus any DC bias **should** not exceed the value established by the derating requirements.

203.2.1.5 Shock

Although these capacitors are resistant to high acceleration loads during acceleration, they are susceptible to damage from mild mechanical shocks. Necessary care should be taken in such applications.

203.2.1.6 Quality Factor "Q"

These capacitors exhibit a much higher “Q” factor over a wider capacitance range than mica dielectric capacitors where “Q” is the ratio of reactance to effective resistance.

203.2.2 Derating Requirements for Styles CYR10, 13, 15, 17, 20, 22, 30, 32, 41, 51, 52, 53

The voltage shall be derated according to the derating curve shown in Figure 200.7. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.7.

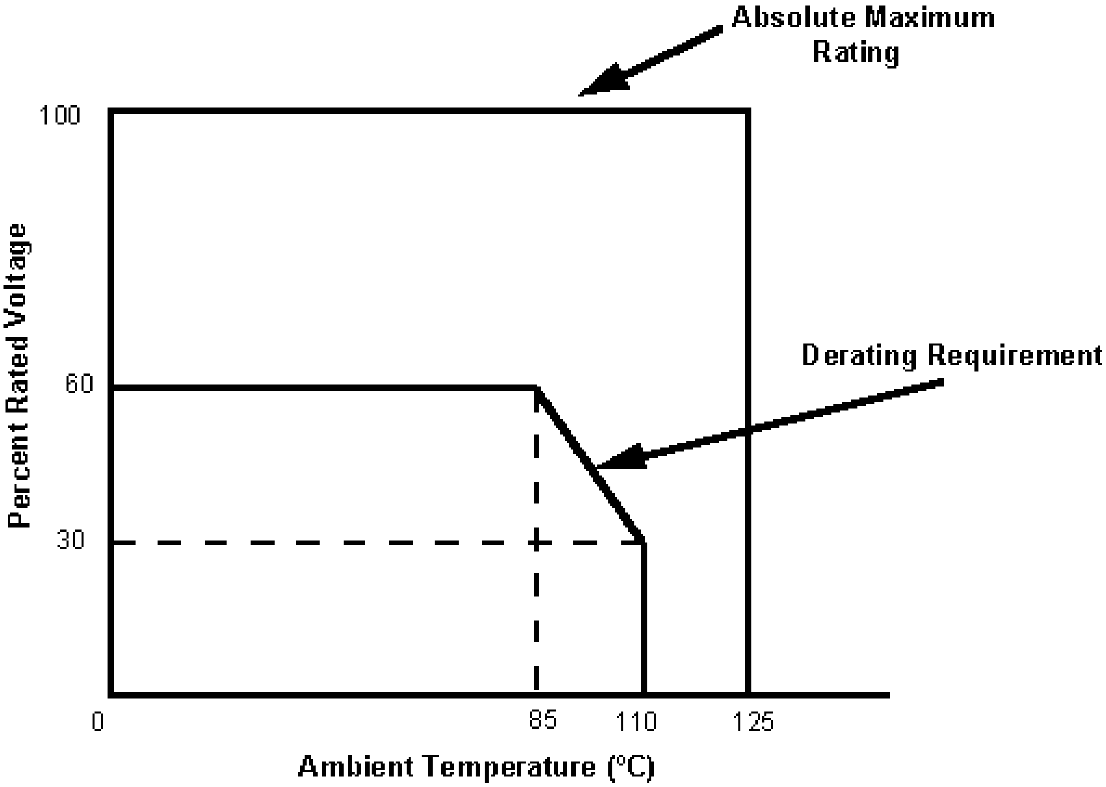


Figure 200.7 -- Derating Requirements for Styles CYR10, 13, 15, 17, 20, 22, 30, 32, 41, 51, 52, 53

203.2.3 Quality Level

Only ER level “R” or higher shall be used.

204 Capacitors, Electrolytic

204.1 General Information

Electrolytic capacitors are smallest in size and cost for a specific capacitance and voltage rating. Although these capacitors are available with high capacitance values, the initial tolerances are large. These capacitors cannot be used where close tolerances are required. Most applications may require surge or ripple current protection to avoid exceeding recommended limits.

204.2 Application Considerations

204.2.1 Shelf Life

Most tantalums particularly those which are either tantalum cased or tantalum lined to prevent silver migration, such as the CLR75, CLR79, and CLR81, have excellent shelf life characteristics. Shelf life of aluminum, however, is limited because the film dissolves in the electrolyte. Tantalum style CLR65 capacitors shall not be used without the approval of the procurement agency.

204.2.2 Case

The largest possible case size should be used for a given capacitor voltage rating as this provides thicker oxide dielectric, lower equivalent series resistance, lower dissipation factor, better heat dissipation, and greater capacitance stability. Only hermetically sealed units shall be used since the penetration of moisture could affect the electrolyte.

204.2.3 Use

Many electrolytic capacitor styles are not hermetically sealed; such capacitors are not suitable for application in low pressure high altitude environments without suitable atmospheric protection. Many of these capacitors are polarized and should not be subjected to reverse bias voltages beyond the limits specified in the derating section.

204.2.4 Operating Frequency

Generally, the filtering capability of these capacitors is limited to frequencies below 10 KHz. Above 10 KHz, the effective capacitance rapidly decreases until the capacitor becomes purely resistive.

204.2.5 Operation in Parallel

When electrolytic capacitors are operated in parallel, the ripple or surge currents will not divide evenly due to the difference in internal impedances.

204.2.6 Tantalum Capacitor Considerations

204.2.6.1 Series Impedance

Most solid tantalum capacitors should have a series impedance of at least 3 ohms/volt (limit charge and discharge currents to 333 mA). This will allow the capacitor to self-heal in the event of momentary dielectric breakdown.

204.2.6.2 Assembly Considerations

When solid electrolytic capacitors are used in parallel banks, series limiting resistors should be installed with each capacitor to prevent discharge of the entire bank into a scintillation fault. When the capacitors are used in series, balancing resistors should be used to assure proper division of voltages. When they are used in banks, they should be assembled in easily removable modules to facilitate replacement and test. Recommended ranges for limiting resistance are .1 - .3 ohms/volt.

204.2.6.3 Ripple Current

The ripple current in capacitors should be limited to values which do not bring the temperature above the derated rating. When capacitors are used in banks it is cautioned that the capacitor with the lowest equivalent series resistance will carry the largest ripple current. For foil and solid electrolytic capacitors, the allowable ripple current should be derated to 80 percent of the manufacturer's maximum ripple current rating. Figure 200.8 provides derating requirements for style CSR tantalum capacitor ripple current.

Figure 200.8 -- Ripple Current Derating for Style CSR Tantalum Capacitors

See Hard Copy for Figure 200.8

204.2.6.4 Reliability Considerations

a. For highest reliability, polarized capacitors shall be protected or applied so that voltage reversal never exceeds 2 percent of the maximum voltage rating. The combined ac and DC voltages shall be analyzed to insure that the worst case conditions do not cause voltage reversals beyond the specified value.

b. The applied voltage and operating temperature shall be limited to the derated values as specified by Table **I-II** and the appropriate derating section of this document.

<u>204.2.7 Aluminum Electrolytic Considerations</u>

Aluminum electrolytic capacitors are intended for use in filter, coupling and bypassing applications where large capacitance values are required in small cases, and where high capacitance tolerances can be tolerated.

Aluminum electrolytic capacitors have in the past experienced deterioration of the oxide film when operated at less than rated voltage for prolonged periods of time. The oxide film deformed to a lower voltage and the capacitor would be destroyed upon application of full rated voltage. This phenomena would also occur if the capacitors were stored for a long period of time, particularly at high temperature. If the capacitors have been in storage for longer than 5 years it is recommended that the capacitors be checked for leakage prior to being used in the circuitry.

204.3 MIL-C-39003, Capacitors, Fixed, Electrolytic (Solid Electrolyte), Tantalum, Established Reliability, (Style CSR)

<u>204.3.1 Application Considerations</u>

These capacitors are intended for use where high capacitance in a small volume is required. Applications include low frequency filtering, bypassing, coupling, blocking and energy storage. They have excellent shelf life. These capacitors are hermetically sealed.

204.3.1.1 Temperature Coefficient

Because of their passive electrolyte being solid and dry, these capacitors have a lower capacitance-temperature characteristic than any of the other electrolytic capacitors.

204.3.1.2 Dielectric Absorption

These capacitors exhibit the characteristic of dielectric absorption whereby a voltage across them will reappear after they have been discharged. This should be considered in their use in RC timing circuits, triggering systems and phase-shift networks.

204.3.1.3 Reverse Voltage

These capacitors shall never be exposed to DC or peak ac voltages greater than 2 percent of their maximum rated DC voltage in the reverse of the normal polarization.

204.3.1.4 Mounting

Supplementary mounting means should be used where the application of these capacitors involves vibration frequencies above 55 Hz.

204.3.2 Derating Requirements for Styles CSR13, 21, 91

The voltage shall be derated according to the derating curve shown in Figure 200.9. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.9. For polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated DC voltage.

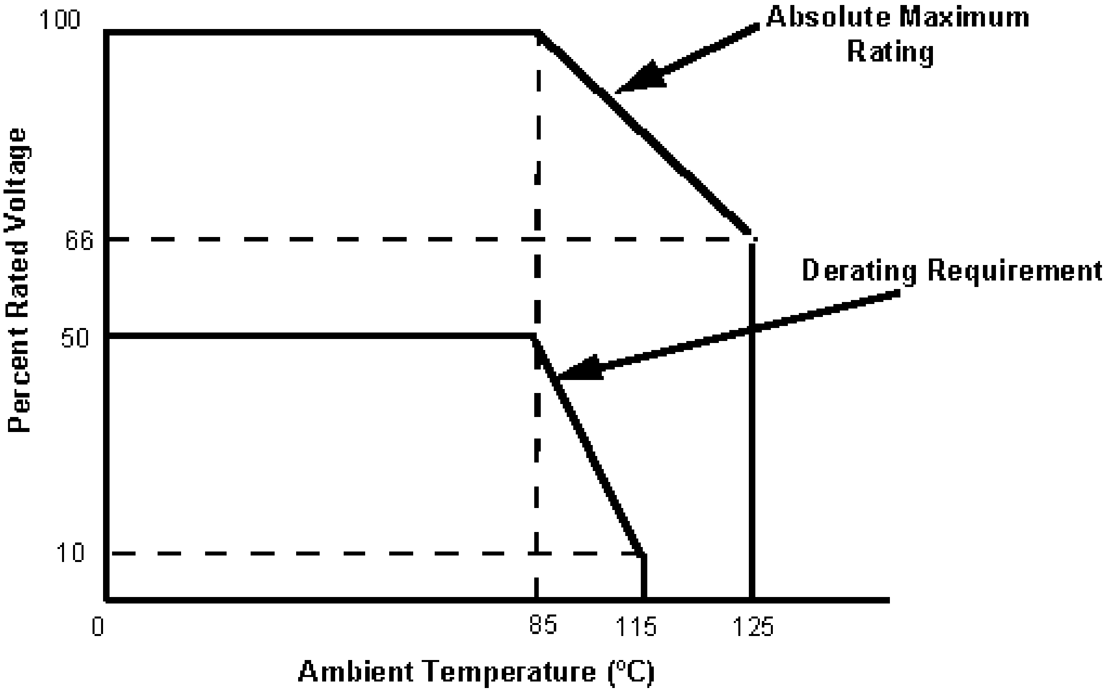


Figure 200.9 -- Derating Requirements for Styles CSR13, 21, 91 and CLR25, 27, 35, 37, 75, 79, 81

204.3.3 Quality Level

Only ER level "R" or higher shall be used.

204.4 MIL-C-39006, Capacitors, Fixed, Electrolytic (Non-Solid Electrolytic) Tantalum, Established Reliability (Style CLR)

204.4.1 Application Considerations

These capacitors are recommended for use where high capacitance is required in a small volume, at medium to high voltages. The non-solid ("wet") electrolyte capacitors fall into three broad categories, which vary substantially in pertinent characteristics.

204.4.1.1 Plain Foil (Styles CLR35 and CLR37)

These capacitors are characterized by their high voltage ratings (up to 450 volts). They are comparatively larger than the sintered slug or etched foil styles for a given capacitance value and have only moderate purchase tolerances (+20 percent).

204.4.1.2 Etched Foil (Styles CLR25 and CLR27)

These capacitors provide substantial improvements in volumetric efficiency over the plain foil styles, and are available in higher voltage ratings than the sintered slug styles. They are characterized by extremely high capacitance values (up to 580 micro farads) but have broad purchase tolerances (+75 percent to -15 percent).

204.4.1.3 Sintered Slug (Type CLR75, 79 and 81)

These styles utilize tantalum cases. These styles of capacitors do not require the silver plating that is required for all other wet tantalum electrolytics because the tantalum case is impervious to attack by H_2S0_4. Other units use steel cases, which must be protected from the sulfuric acid electrolyte. See paragraph 204.4.1.10 for selection preferences.

204.4.1.4 Life Tolerance

As described above, these capacitors come with various tolerances from -15 percent to +75 percent. However, regardless of the purchase tolerance, the design should be able to tolerate an additional 10 percent reduction in capacitance as compared to the initial value, to compensate for the cumulative effects of temperature and aging over the life of these capacitors.

204.4.1.5 Polarization

CLR style capacitors are polarized except for styles CLR27 and CLR37. Non-polarized styles are primarily suitable for ac applications or where DC voltage reversals can occur. Examples of these uses are in:

(a) tuned low-frequency circuits;

(b) phasing of low voltage ac motors;

(c) computer circuits and

(d) servo systems.

204.4.1.6 Series Operation

Whenever these capacitors are connected in series for higher voltage operation, a resistor shall be in parallel across each unit. Unless a shunt resistor is used, the DC rated voltage can easily be exceeded on **a** capacitor in the series network depending upon the capacitance, the average DC leakage and the capacitor construction.

204.4.1.7 Parallel Operation

When these capacitors are operated in parallel, care **should** be taken to assure that the sum of the peak voltage ripple and the applied DC voltage does not exceed the DC rated voltage. The connecting leads of the parallel network should be large enough to carry the combined currents without reducing the effective capacitance resulting from series lead resistance.

204.4.1.8 High Capacitance Series

It is not recommended to select the highest capacitance value available for a given voltage rating and case size. In some of the MIL-C-39006 detail specifications, these capacitors are flagged by an "*". Reasons for not selecting these capacitors are:

a. They represent the ultimate in the capability of the manufacturing process, and are thus less predictable, and inherently less reliable.

b. They are typically much more expensive than the lower capacitance values in the same voltage rating and case sizes.

c. In the manufacture process, the "forming" voltage will generally be lower (as a ratio of the rated operating voltage) than for lower capacitance values, providing a lesser margin of safety.

d. They will typically exhibit a greater decrease of capacitance at low temperature, and thus provide only an illusion of higher capacitance in the actual operating environment.

204.4.1.9 Hermetic Seal

Only hermetically sealed capacitors shall be used. The use of the liquid or gelled electrolyte absolutely precludes the use of non-hermetic types. The non-hermetic types have been proven unreliable because the electrolyte can escape, either in a liquid or gaseous form, reducing the capacitance and causing catastrophic failure under extended exposure to military service environments.

204.4.1.10 Restricted Use of Wet Slug Tantalum Capacitors

The order of preference for the selection of the types described above is as follows:

a. Sintered Slug, Tantalum Case (Style CLR79**, 81)**

b. Plain Foil (Styles CLR35 and CLR37)

c. Etched Foil (Styles CLR25 and CLR27)

d. Tantalum lined, silver cased, sintered slug (CLR75)

Wet slug tantalum capacitance cannot be used on Naval Air Systems Command Programs without approval of the procuring agency. Wet slug capacitors other than MIL-C-39006/22 (CLR79) and MIL-C-39006/25 (CLR81) shall not be used on other programs without approval of the procuring agency.

204.4.2 Derating Requirements for Styles CLR25, 27, 35, 37, 75, 79, 81

The voltage shall be derated according to the derating curve shown in Figure 200.8. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.9. For polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated voltage.

204.4.3 Quality Level

Only ER level "R" or higher shall be used.

204.5 MIL-C-39018, Capacitors, Fixed, Electrolytic (Aluminum Oxide), (Style CUR), Established Reliability and (Style CU), Non-established Reliability

204.5.1 Application Considerations

These capacitors are generally used for filtering low frequency, pulsulating, DC signal components in B power supplies up to 400 Vdc. These capacitors are used at such points as plate and screen connections to B+, and cathode bypass capacitors in self-biasing circuits. These capacitors are designed for applications where variations in capacitance are relatively important. These capacitors are ***not*** recommended for Navy application and require procuring activity approval prior to use.

204.5.1.1 Operating Frequency

These capacitors are recommended for use over the frequency range 60 to 10,000 Hz.

204.5.1.2 Polarization

Styles (CUR13, 17, 19, 71 and 91) are polarized. In applications where reversal of polarity occurs, only style CU15 shall be used. The polarized capacitors (CUR13, 17, 19, 71 and 91) shall be used only in DC circuits with polarity properly observed. Style CUR13 and CUR17 have a 3-volt reverse voltage limitation for units rated at 10 volts or greater. Styles CUR19, 71, and 91 have reverse voltage limitations of 1.5 volts. If ac components are present, the sum of the peak ac voltage plus the applied DC voltage shall not exceed the derated value. The proper polarity shall be maintained even on negative peaks, to avoid overheating and damage.

204.5.1.3 Seal

Even though these capacitors have vents designed to open at dangerous pressures, explosions can occur because of gas pressure build-up or a spark ignition of free oxygen and hydrogen liberated at the electrode. Provisions should be made to protect surrounding parts.

204.5.1.4 Environmental Conditions

These capacitors should not be subjected to low barometric pressures and low temperatures. Therefore they shall not be used for airborne applications without prior approval by the procuring activity.

204.5.1.5 Surge Voltage

The surge voltage is the maximum voltage to which the capacitor **may** be subjected. This includes transients and peak ripple at the highest line voltage. For maximum reliability and long life, the DC working voltage should not be more than 60 percent of the full voltage rating so that surges can be kept within the full-rated working voltage. Surge-voltage application should not occur more than 30 seconds every 10 minutes.

204.5.1.6 Cleaning Solvents

Recommended solvents include those free of halogen or halogen groups, such as toluene, methanol, methylcellusolve, alkinox and water, and naphtha. Chlorinated or fluorinated hydrocarbon solvents shall not be used for cleaning these capacitors.

204.5.2 Derating Requirements for Style CUR71

The voltage shall be derated according to the derating curve shown in Figure 200.10. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.10. For the polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated DC voltage.

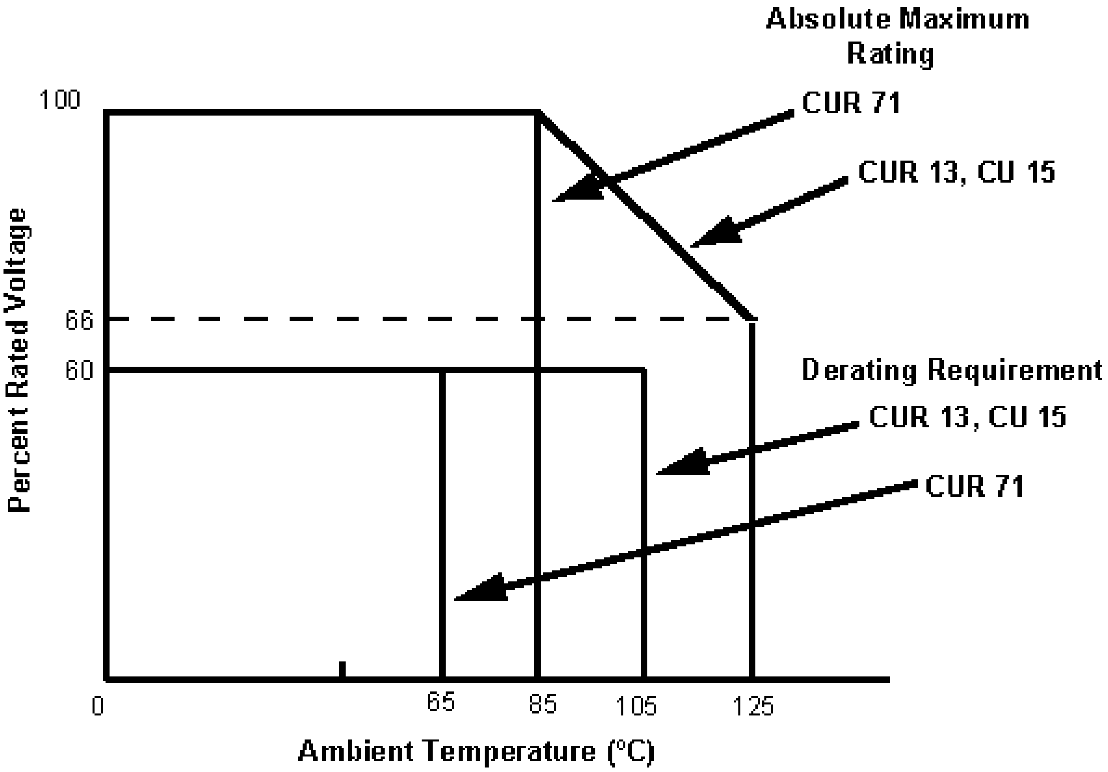


Figure 200.10 -- Derating Requirements for Style CUR13, 71, and CU15

204.5.3 Derating Requirements for Styles CUR17, 19, and 91

The voltage shall be derated according to the derating curve shown in Figure 200.11. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.11. For the polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated DC voltage.

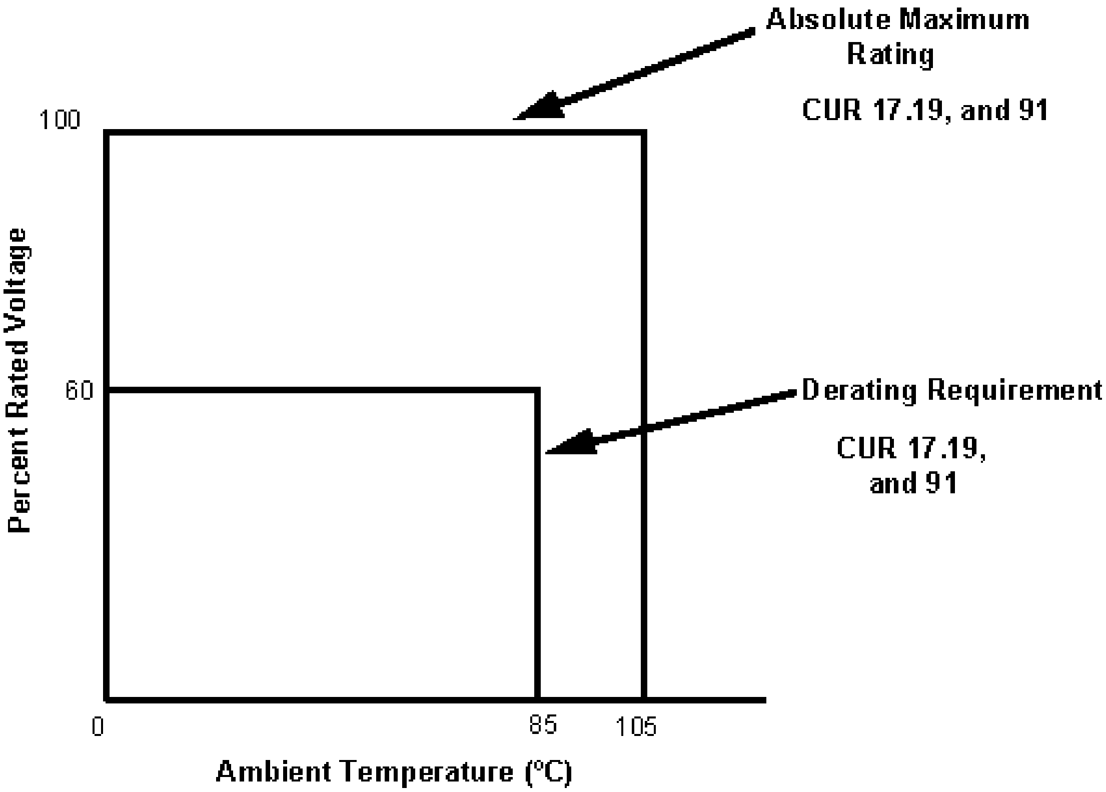


Figure 200.11 -- Derating Requirements for Styles CUR17, 19, 91

204.5.4 Derating Requirements for Styles CUR13 and CU15

The voltage shall be derated according to the derating curve shown in Figure 200.10. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.10. For polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated DC voltage.

204.5.5 Quality Level

Only ER level “R” or higher shall be used.

205 Capacitors, Mica Dielectric, Fixed

205.1 Application Considerations

205.1.1 Construction

Both glass and mica capacitors have high capacitance per unit, volume or mass with the glass usually having a much higher capacitance to its volume/mass ratio than the mica. Bodies of these capacitors are often made of dielectric material and are capable of resisting moisture to a large degree. These capacitors are very brittle due to their construction and materials used and may be damaged by high shock or vibration.

205.1.2 Operating Frequency

These capacitors perform well at high frequencies up to 500 MHz.

205.1.3 AC Operation

When AC operation is required, the peak AC voltage plus any DC bias shall not exceed the values established by the derating requirements. Where transients are encountered, the effects of these transients should also be taken into consideration when selecting capacitors.

205.1.4 Environmental Considerations

Silvered-mica capacitors should never be subjected to DC voltage stresses in combination with high humidity and high temperatures for extended periods due to silver-ion migration effects.

205.2 MIL-C-39001, Capacitors, Fixed, MICA Dielectric, Established Reliability, (Style CMR)

205.2.1 Application Considerations

These capacitors are designed for use in circuits requiring precise high frequency filtering, bypassing, and coupling. They are used where close impedance limits are essential with respect to temperature, frequency, and aging -- such as in tuned circuits which control frequency, reactance, or phase. These capacitors are also useful as padders in tuned circuits, as secondary capacitance standards, and as fixed-tuning capacitors at high frequencies. They can also be employed in delay lines and stable low-power networks.

Due to the inherent characteristics of the dielectric (i.e., high insulation resistance and high breakdown voltage, low power factor, low inductance, and low dielectric absorption), these capacitors, have good stability and high reliability. They are available in small sizes.

205.2.1.1 Capacitance Tolerance

These capacitors come with tolerances of ±0.5 pf, ±1 percent, ±2 percent and ±5 percent. However, regardless of the purchase tolerance, the design should tolerate a ±0.5 percent change in capacitance value to assure long life reliability in military applications.

205.2.1.2 Operating Frequency

These capacitors perform very well at frequencies up to 500 MHz with a typical operating frequency range of 10 kHz to 500 MHz.

205.2.1.3 Insulation Resistance

These capacitors have very high insulation resistance and low dissipation factors.

205.2.2 Derating Requirements for Styles CMR03

The voltage shall be derated according to the derating curve shown in Figure 200.1**2**. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.1**2**. These derating requirements only apply to those capacitors having a rated temperature range of -55ºC to +125ºC.

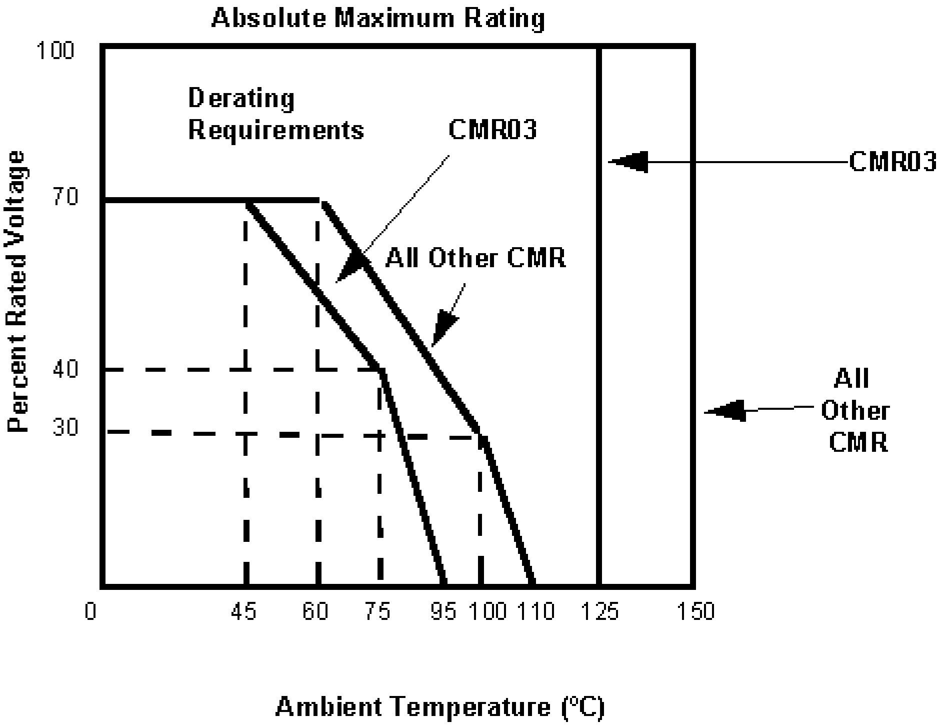


Figure 200.12 -- Derating Requirements for Styles CMR03, 04, 05, 06, 07, 08 with a Rated Temperature to 125ºC

205.2.3 Construction

These capacitors are fixed terminal capacitors employing the use of tin-lead foil.

205.2.4 Derating Requirements for Styles CMR04, 05, 06, 07, 08

The voltage shall be derated according to the derating curve shown in Figure 200.12. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.12. These derating requirements only apply to those capacitors having a rated temperature range of -55ºC to +150ºC.

205.2.5 Quality Level

Only ER level “R” or higher shall be used.

206 Capacitors, Paper/Plastic/Paper -- Plastic Dielectric

206.1 General Information

These capacitors can be used in applications that require high and stable dielectric resistance at high temperatures and good capacitance stability over a wide temperature range. This permits use in a wide range of applications ranging from computers to guided missiles. The relatively high dielectric strength of some of the plastic capacitors can lead to attractive small physical dimensions. These capacitors are of a small relative size for equivalent CV rating except for MIL-C-19978 polystyrene types which are medium to large size. Metallized paper capacitors have low dielectric resistance and are prone to dielectric breakdown. Plastic dielectric capacitors have superior moisture characteristics in that they are non-absorbent.

206.2 Application Considerations

206.2.1 Seal

All units shall be hermetically sealed. Small amounts of moisture can increase the rate of chemical reactions within the capacitor materials.

206.2.2 Mounting

Capacitors with lengths of 1.375 or widths of 0.672 inches or greater should not be supported by their leads. These capacitors should be provided with a supplementary means for mounting, such as tangential brackets. To keep the inductance to a minimum, the capacitors should be installed close to the source so that the lead length is as short as possible. The output lead should be kept away from the input lead. In severe cases the input lead should be shielded. Good bonding is extremely important in the installation of capacitors.

206.2.3 AC Operation

When AC operation is required, care should be taken to ensure that: (a) the sum of the DC voltage and the peak ac voltage does not exceed the value established by the derating requirements; and (b) the ac voltage does not exceed 2O percent of the value established by the derating requirements or the value calculated from the following equation, whichever is smaller:

$$V_p\,(ac) \sqrt{\frac{(T_{dc} - T)\, Ae}{(\pi)\,(f)\,(C)\,(D)}}$$

Figure 206:2.3

Where:

$V_p($	Peak value of ac component

ac)

f	Frequency of ac component (Hz)
D	2 (maximum Dissipation Factor (DF) at applicable high test temperature)
C	Nominal capacitance in farads
A	Exposed capacitor case surface area in square centimeters (cm)^2 exclusive of portion occupied by terminal mountings
Tdc	Applicable high test temperature in degrees Celsius
T	Maximum ambient operating temperature expected within equipment containing capacitor
e	Convection coefficient in watts per cm^2/ºC (The value of "e" is approximately equal to 0.0006).

206.2.4 Faults or "Clearings"

For metallized paper and plastic capacitors with conducting plates having thicknesses in the micrometer or submicrometer range, a puncture of the thin dielectric due to voltage stress can in turn cause a relatively harmless vaporization of a small area of the plates. The clearing of such faults is due to high peak currents at fault sites when metal vaporization around the pin holes corrects the shorts. These events normally occur with voltage spikes and result in small reductions in capacitor values. These phenomena are not considered failures of the capacitor until enough of them occur to cause the capacitor value to be outside the specified tolerance. These capacitors are not suitable for use in low voltage, high impedance circuits, since insufficient energy is available to burn such faults away.

206.3 MIL-C-19978, Capacitors, Fixed, Plastic (or Paper-Plastic), Dielectric (Hermetically Sealed in Metal Cases), Established Reliability, (Style CQR)

206.3.1 Application Considerations

206.3.1.1 Use

These capacitors are designed for use in circuit applications requiring high insulation resistance, low dielectric absorption, or low loss factor over wide temperature ranges, and where the ac component of the impressed voltage is small with respect to the DC voltage rating. These capacitors are broadly categorized into three characteristic groups as follows:

a. Polyethylene terephthalate (characteristic M capacitors) -- Characteristic M capacitors are intended for high temperature applications similar to those served by hermetically-sealed paper capacitors. These capacitors also exhibit high insulation resistance at the upper temperature limits.

b. Paper and polyethylene terephthalate (characteristic K capacitors) -- Characteristic K capacitors are intended for applications where high insulation resistance is necessary.

c. Polycarbonate (characteristic Q capacitors) -- Characteristic Q capacitors are intended for applications where minimum capacitance changes with temperature are required. These capacitors are especially suitable for use in tuned and precision timing circuits.

d. Capacitance tolerance -- These capacitors come with tolerances of +2 percent, +5 percent, +10 percent. However, regardless of the purchase tolerance, designs using these capacitors should tolerate a +2 percent change in capacitance value to assure long life reliability in military applications.

206.3.1.2 AC Operation

Whenever ac operation is required, care should be taken to ensure that: (a) the sum of the DC voltage and the peak ac voltage does not exceed the value established by the derating requirements; or (b) the peak ac voltage does not exceed 20 percent of the DC voltage established by the derating requirements at 60 Hz, 15 percent at 120 Hz; or 1 percent at 10,000 Hz. Where heavy transient or pulse currents are encountered, the requirements of MIL-C-19978 are not sufficient to guarantee satisfactory performance. This should be considered in the selection of a capacitor.

206.3.1.3 Barometric Pressure (Flashover) for Metal-Cased Tubular Capacitors

The DC voltage that can be applied to metal-cased tubular capacitors at different altitudes can be obtained from Figure 200.13. The DC voltage shall not exceed the specified derating levels.

Figure 200.13-- DC Voltage at Different Altitudes for Metal Case Tubular Capacitors

See Hard Copy for Figure 200-13

206.3.2 Derating Requirements for Styles CQR29, 32, 33

The voltage shall be derated according to the derating curve shown in Figure 200.14. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.14.

206.3.3 Derating Requirements for Styles CQR07, 09, 12, 13

The voltage shall be derated according to the derating curve shown in Figure 200.14. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.14.

206.3.4 Quality Level

Only ER level “R” or higher shall be used.

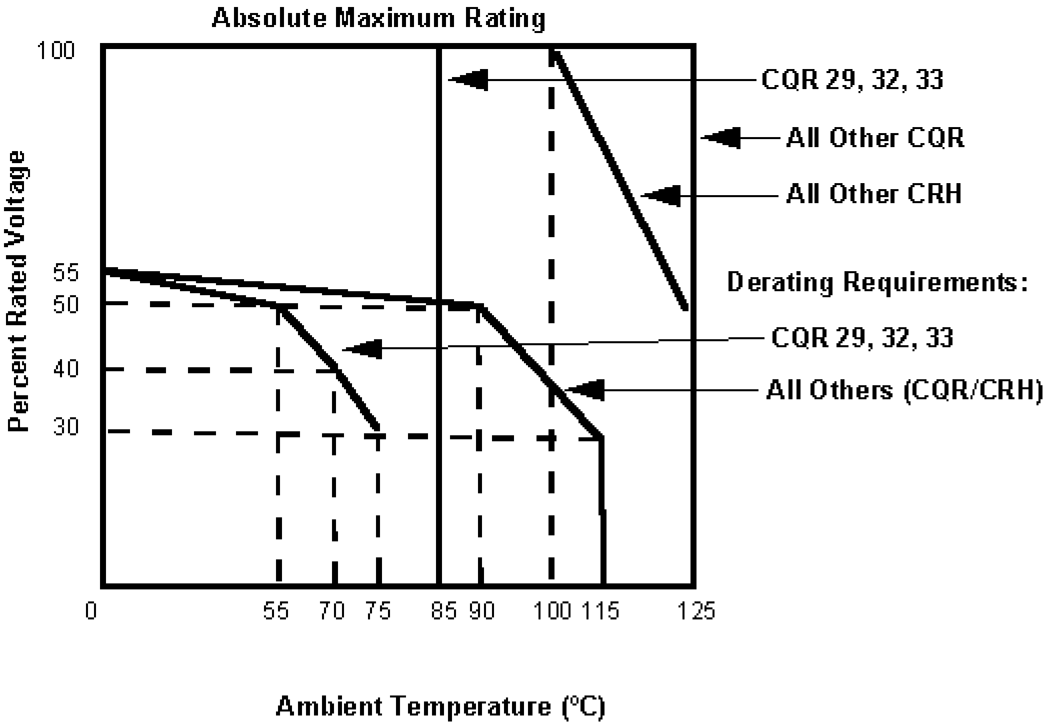


Figure 200.14 -- Derating Requirements for Styles CQR07, 09, 12, 13, 29, 32, 33, and CRH 01, 02, 03, 04, 05

206.4 MIL-C-39022, Capacitors, Fixed, Metallized, Paper Plastic Film or Plastic Film...

Dielectric, Direct and Alternating Current (Hermetically Sealed in Metal Cases), Established Reliability, (Style CHR)

206.4.1 Application Considerations

These capacitors are primarily intended for use in power supply filter circuits, bypass applications, and other applications where: (a) the ac component of voltage is small with respect to the DC voltage rating, and (b) where occasional periods of low insulation and momentary breakdowns can be tolerated. These capacitors are available in a wide range of capacitance values and voltage ranges and offer low dielectric absorption.

206.4.1.1 Capacitance Tolerance

These capacitors come in tolerances of +5. percent add +10 percent. However, regardless of the purchase tolerance, the design should be able to tolerate a +2 percent change in capacitance value to assure long life reliability in military applications.

206.4.1.2 Capacitance-Temperature Characteristics

The capacitors with “Mylar” or polycarbonate dielectric offer very low (on the order of +1 percent) capacitance change with temperature over the operating temperature range.

206.4.2 Derating Requirements for Styles CHR09, and 49

The voltage shall be derated according to the derating curve shown in Figure 200.15. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.15.

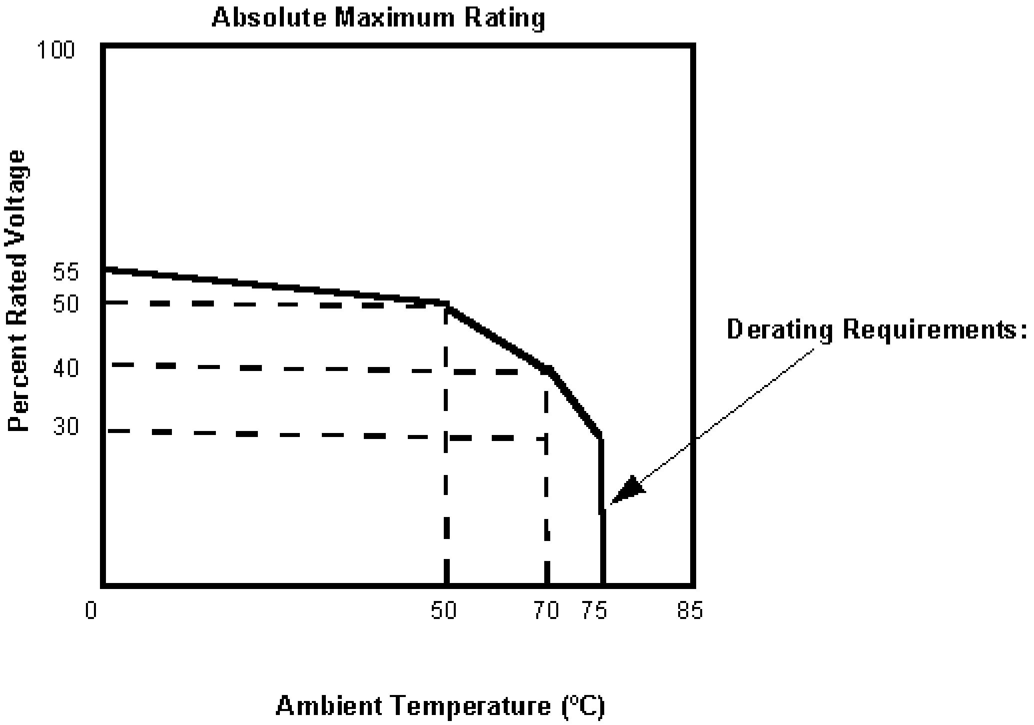


Figure 200.15 -- Derating Requirements for Styles CHR09, 49

206.4.3 Quality Level

Only ER level “R” or higher shall be used.

207 Film Capacitors, Plastic Dielectric

207.1 MIL-C-83421 Capacitors, Fixed, Supermetallized, Plastic Film Dielectric, (DC, AC, or DC and AC), Hermetically Sealed in Metal Cases, Established Reliability, (Style CRH)

207.1.1 Application Considerations

207.1.1.1 Use

Capacitors covered by this specification are primarily intended for use in circuit applications which require non-polar behavior, relatively high insulation resistance, low dielectric absorption, low capacitance change with temperature, and low capacitance drift over the temperature range. Styles covered by this specification are rated for continuous operation under ac sinusoidal conditions in addition to continuous operation under DC conditions. These capacitors can exhibit periods of low insulation resistance and should only be used in circuits that can tolerate occasional momentary breakdowns. They should not be used in high impedance, low voltage applications.

207.1.1.2 Voltage Rating

DC ratings vary from 30 Vdc to 400 Vdc over the temperature range of -55ºC to +100ºC.

AC ratings vary from 22 Vrms to 240 Vrms at 400 Hz over the temperature range of -55ºC to +100ºC. Operation at frequencies above 40 kHz is permissible provided the derated rms voltage limit at 400 Hz is not exceeded. AC and DC voltage ratings are decreased to 67 percent of the 25ºC rating at 125ºC.

The sum of the combined DC and ac peak voltage should not exceed the value established by the derating requirements.

207.1.2 Derating Requirements for Styles CRH01, 02, 03, 04, 05

The voltage shall be derated according to the derating curve shown in Figure 200.14. The ambient temperature shall be limited to the derated maximum value shown in Figure 200.14.

207.1.3 Quality Level

Only ER level “R” or higher shall be used.

208 Chip Capacitors

208.1 MIL-C-55681, Capacitors, Chip, Multilayer, Fixed Ceramic Dielectric, Established Reliability (Style CDR)

208.1.1 Application Considerations

208.1.1.1 Use

These capacitors are intended for use in thin or thick film hybrid circuits.

208.1.1.2 Capacitance Tolerance

These capacitors are available with capacitance tolerances of ±5%, ±10% and ±20%.

208.1.1.3 AC Operation

In AC operation, the sum of the AC and any DC bias should not exceed the value established by the derating requirements.

208.1.1.4 Effect of Mounting

Voltage-temperature limits, resistance to thermal shock, and reliability can be affected as a result of mounting on substrates with dissimilar coefficients of expansion from capacitor material. Care should be taken in the selection of substrate material.

208.1.2 Derating Requirements for Styles CDR01, 02, 03, 04

The voltage shall be derated according to the derating curve shown in Figure 200.16. The ambient temperature shall be limited to the derated maximum value shown in Figure 200.16.

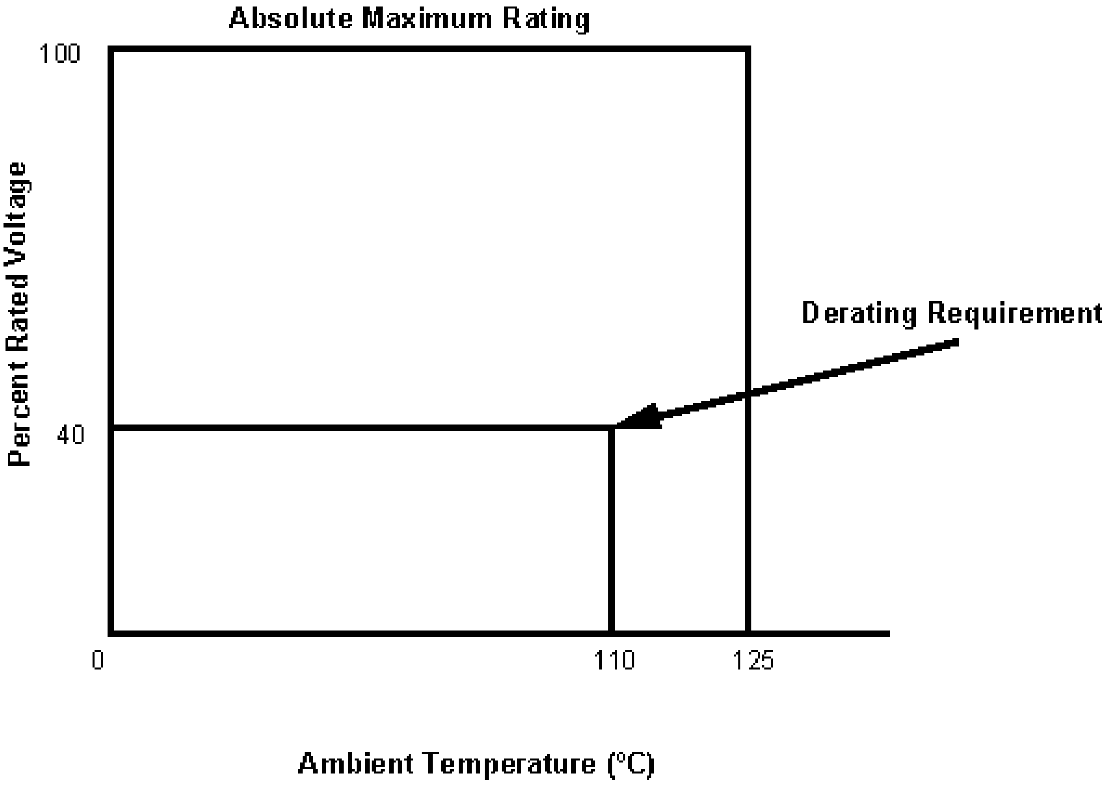


Figure 200.16 -- Derating Requirements for Style CDR

208.1.3 Quality Level

Only ER level “R” or higher shall be used.

208.2 MIL-C-55365, Capacitors, Chip, Fixed, Tantalum, Established Reliability (Style CWR)

208.2.1 Application Considerations

208.2.1.1 Use

These capacitors are primarily intended for use in thick and thin film hybrid circuits for filtering, bypassing, coupling, and other applications where the AC component is small compared to the DC rated voltage. These capacitors should be used only where moisture protection is provided.

208.2.1.2 Surge Voltage

The surge voltage should not exceed 130% of the value established by the derating requirements.

208.2.1.3 AC Operation

In AC operation, the sum of the AC peak plus any DC voltage should not exceed the value established by the derating requirements.

208.2.1.4 Mounting

These capacitors are designed for mounting by reflow solder or conductive epoxy in circuit substrates. The use of a heat column or controlled hot plate is recommended for reflow procedures. Caution must be exercised to limit temperature to 300 ºC maximum during reflow or premature degradation of the solid electrolyte will occur. Conductive epoxies and solder paste creams are very useful in production situations because they can be accurately and rapidly screened on to the pads using masks. Also, they have a pre-cure tackiness permitting chip placement before the epoxy is cured. Conductive epoxies have the advantage of low temperature curing, however the cold temperature cure characteristics of physical strength and conductivity may not be as good as some soft solders. To prevent thermal shock, the substrate with the chip capacitors in place should be heated slowly to the reflow temperature.

208.2.2 Derating Requirements for Styles CWR02, 03, 04, 05, 06, 07, 08

The voltage shall be derated according to the derating curve shown in Figure 200.17. The ambient temperature shall be limited to the derated maximum value shown in Figure 200.17.

Figure 200.17 -- Derating Requirements for Styles CWR02, 03, 04, 05, 06, 07, 08

208.2.3 Quality Level

Only ER level “R” or higher shall be used.

Next Section

Previous Section

Section 300 -- Discrete Semiconductor Devices

300 Discrete Semiconductor Devices

300.1 General Information

Standard semiconductor devices are those listed in MIL-STD-701. These devices are a subset of those meeting the general requirements of MIL-S-19500 and the detailed requirements of MIL-S-19500 detail specifications.

300.1.1 Device Parameter Drifts

Semiconductor devices may exhibit change in parameter values over their life within specified limits. Therefore, for long life reliability the design should be able to tolerate a shift in the parameters as shown in Table 300.1:

Table 300.1 -- Device Parameter Tolerance

Parameters	**Diodes**	**Transistors**	**Thyristors**
Gain:			
(a) Initial	--	±10%	--
(b) Match	--	±20%	--
Leakage (off state) Current	+100%	+100%	+100%
Recovery, switching times	+20%	+20%	+20%
Junction voltage drop:			
(a) Forward, saturation	±10%	±10%	±10%
(b) Forward, match	--	+50%	--
Zener -- Regulator	±2%	--	--
Zener -- Reference	±1%	--	--

300.1.2 Sealing

Only hermetically sealed devices shall be used. No plastic (organic or polymeric) encapsulated or sealed devices shall be used without the approval of the procuring activity.

300.1.3 Uncontrolled Characteristics

Satisfactory equipment performance should not depend on a semiconductor device characteristic which is not controlled by the applicable MIL-S-19500 detail specification.

300.1.4 Electrostatic Damage Sensitivity

All semiconductor devices are susceptible to electrostatic discharge (ESD) damage. Appropriate procedures compatible with DOD-STD-1686 and DOD-HDBK-263 shall be used when handling these parts, and selection of devices should include an analysis of the input protection circuitry.

300.1.5 Power Dissipation

The failure rate of semiconductor devices increases dramatically as the junction temperature increases. To calculate the junction temperature the following equation is used:

$$\mathbf{T_J = T_A + (\theta_{JA} \times P_d)}$$

Where:

T_J - Junction Temperature

T_A - Ambient temperature (i.e., the temperature of the air surrounding the part)

P_d = Power dissipation of the device

θ_{JA} = Thermal resistivity, junction to ambient, expressed in ºC/W or ºC/mW

The thermal resistivity should be given in the specification sheet, although it may not be given directly.θ_{JC}, junction to case thermal resistivity, and θ_{CA}, case to ambient thermal resistivity, may be given instead, but $\theta_{JA} = \theta_{JC} + \theta_{CA}$.

If the case temperature, T_C, is known instead of the ambient, an alternate equation can be used.

$$T_J = T_C + (\theta_{CA} \times P_d)$$

300.1.6 Power Derating Requirements

Semiconductor device data sheets generally give maximum power dissipation up to a maximum temperature, T_S. Beyond this temperature it is required to linearly derate power to not exceed the maximum junction temperature, T_{jMax}, as shown by the absolute maximum derating curve in Figure 300.1. T_S may be given as either a maximum case temperataure ($T_{CMAX)}$ or an ambient temperature ($T_{AMAX)}$, either of which will give identical results.

Power shall be derated 50% as shown by the maximum allowable derating curve in Figure 300.1. Beyond T_S the power shall be linearly derated to the derating temperature, T_D, defined as:

$$T_D = \frac{T_s + T_{JMAX}}{2}$$

Note: The slope of the derating curve is equal to the inverse of θ_{JA} or θ_{JC} depending on whether T_A or T_C is used as T_S, respectively.

300.2 Diodes

A diode is a semiconductor device which has two semiconductor layers which allow current to flow in essentially only one direction. This manual divides diodes into two categories, rectifier diodes, and zener diodes. For most applications diode T_{jMax} should be 110ºC.

300.2.1 Rectifier Diodes

a. ***Description*** -- An ideal rectifier diode has zero resistance under forward voltage bias conduction and infinite resistance under reverse blocking, allowing current to flow in only one direction. Most diode rectifiers are constructed from Silicon (Si), although Germanium (Ge) devices still exist, and Gallium Arsinide (GaAs) devices are expected to be approved for usage in the near future. For new designs, Ge devices shall not be used in military applications without approval from the procuring activity. GaAs has several advantages over Si, such as operation at higher frequencies with less power dissipation. Although, GaAs has experienced reliability problems in the past, current research is expected to result in achieving significant reliabilility improvements for GaAs devices.

b. ***Applications*** -- Rectifier diodes should have I-V characteristics as close as possible to that of an ideal diode. The six major design parameters used in the selection of a diode are the forward current, wattage, reverse voltage, forward voltage drop, reverse leakage current, peak surge current, and reverse recovery time. From a reliability standpoint, forward voltage drop is the most important parameter because the majority of heat dissipation occurs during forward conduction. The materials used to make diodes (Si, Ge or GaAs) have resulted in this parameter being fairly constant for all devices.

When diodes are used in high power or high speed applications a fast recovery time is needed. When a diode is switched from forward conduction to reverse blocking, the current will not fall immediately to its near zero leakage current because of the capacitively charged depletion layer. In addition to this switching (or state transition) delay, a high power dissipation spike usually occurs.

c. ***Reliability Information*** -- Because rectifiers are steadily being used in higher power applications, heat dissipation is becoming a major concern. For devices used in low power circuits, glass or plastic (if approved) encapsulation, or simple header mounting is adequate. However, high power diodes must be specifically mounted to transfer thermal energy away from the p-n junction. Power rectifiers are generally mounted on molybdenum or tungsten. It should be noted that selection of plastic encapsulation devices is normally not permitted. disks to match the thermal expansion properties of the silicon. This disk is then fastened to a large copper or other thermally conductive material that can be bolted onto a heat sink.

To achieve reliable design there are four design parameters which shall be derated: power, forward surge current, inverse voltage and transient voltage. Maximum steady state power shall be derated as shown in Figure 300.1, and current shall be derated in accordance with Figure 300.2. If other factors, such as high switching frequencies, cause the junction temperature to rise above the maximum steady state value, the power shall be further derated.

Close attention should be given to transient voltages when designing high power inverters and converters. The usually encountered high inductance loads can cause excess transients to develop.

300.2.2 Zener Diodes

a. ***Description*** -- A zener diode, also known as a breakdown, avalanche breakdown, or reference diode, is defined as a diode which is designed to specifically operate in its breakdown region. A zener diode operates identically to a rectifier diode under forward conduction and up to its Zener voltage in the reverse blocking mode. At the onset of its zener voltage it begins to “break down”, that is, it loses reverse blocking capability and begins to sink current. Ideally, the maximum reverse voltage that can appear across a zener diode under normal operating conditions is its zener voltage.

For zener diodes rated below 5V, the breakdown mechanism is caused by a quantum tunneling effect. Above 7V another mechanism called avalanche breakdown is responsible, and between 5 and 7V a combination of the two takes place. Even though avalanche breakdown, not the zener effect, causes breakdown at high voltages, they are still all named zener diodes.

b. ***Application*** -- Zener diodes are used in applications in which certain potential thresholds are not to be exceeded. The circuits may take the form of voltage regulators, voltage references, or some type of protection network.

An ideal zener diode has infinite resistance below the zener voltage and zero resistance above it. Actually, as the reverse voltage approaches the zener voltage the resistance decreases at an increasing rate. This point is normally called the knee current or knee voltage. The resistance then becomes a constant called the dynamic resistance. The lower the dynamic resistance the more effective the zener diode is as a voltage regulator.

Low voltage zener diodes (5v) that break down because of the zener effect suffer from a problem called “weak knees”. That is, they do not display well defined and sharp breakdown knees and thus do not function as well as desired. When such low voltage zener diodes are considered, it may be more desirable to use instead several forward biased standard diodes in series. However, since low voltage zeners have very high dynamic

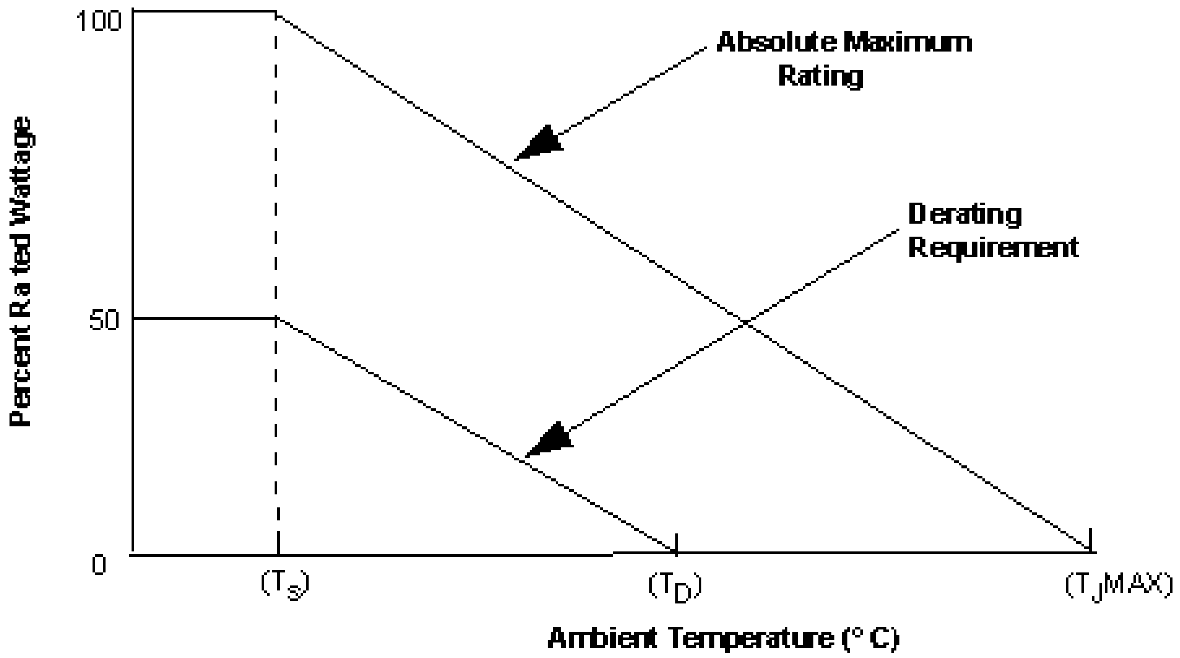


Figure 300.1 -- Diode/Transistor Power Derating Curve

resistances, using standard diodes in series may significantly lower the effective dynamic resistance. This should be considered in the event of this kind of design tradeoff.

Zener diodes are manufactured in a variety of standard voltages. To achieve a more exact breakdown voltage, two or more zener diodes are often connected in series. When a high voltage zener is needed, it is usually more advantageous to install two or more diodes in series rather than a single diode. This allows for more effective heat dissipation.

c. ***Reliability Information*** -- Zener diodes shall be power derated as shown in Figure 300.1. However, zeners are often used in circuits as protection elements where they only sink current under abnormal conditions. Under these circumstances, it may not be necessary to derate the device to such an extent, and higher derating values can be, used with Procuring Activity approval.

An important reliability parameter is the temperature coefficient (K_T) in units of mV/ºC. This parameter defines the change in zener voltage due to change in operating temperatures.K_T is usually a positive number except for low voltage (5v) zeners, and standard rectifier diodes, where it may be zero or negative. A typical standard diode has a K_T of -2mV/ºC. Therefore, it is possible to connect zener diodes in series with standard diodes, and have the positive and negative temperature coefficients cancel each other out, resulting in little or no overall voltage variance with temperature.

The K_T can cause further complications because it is not always a constant. As the forward current increases the temperature coefficient also increases.

300.3 Opto-Electronic Semiconductor Devices

a. ***Description*** -- Opto-electronic semiconductor Devices are classified as Light Emitting Diodes (LEDs), Opto-electronic Couplers (Isolators), LED Alpha-numeric Displays, phototransistors, and photodiodes. An opto-electronic semiconductor device is defined as a device that converts electrical energy into light energy, light to electrical energy, or both. A more detailed description is given in Sections 300.6.1 and 300.6.2 under photoemitters and photodetectors for fiber optic systems.

b. ***Application*** -- Opto-electronic semiconductors are most commonly used in some type of optical displays. This may be in the form of warning lights, for example, or 7-segment displays. Also, Opto-electrical couplers can be used as filters for noise suppression. These are commonly called opto-isolators or photo-isolators. More recently, opto-electronic semiconductors have been used in fiber-optic systems.

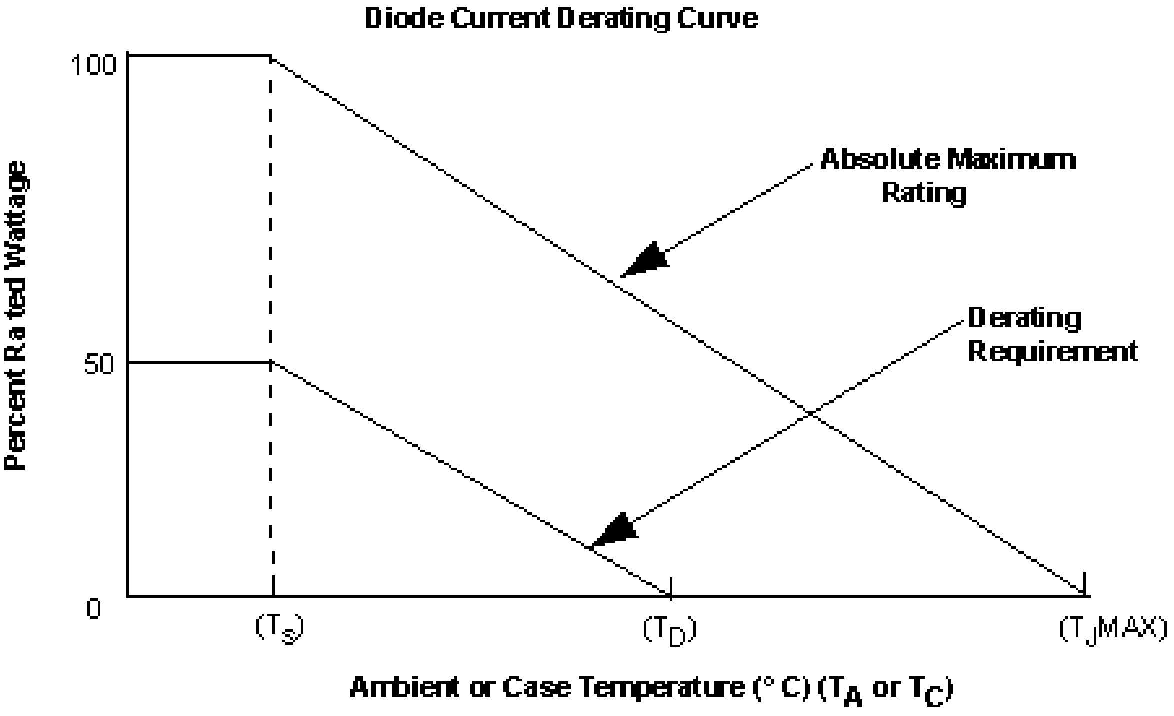


Figure 300.2 -- Diode Current Derating Curve

c. ***Reliability Information*** -- Opto-electronic semiconductor devices shall have a power derated as shown in Figure 300-1. More detailed reliability information is given in Sections 300.6.1 and 300.6.2.

300.4 Transistors

a. ***Description*** -- Transistors are three terminal semiconductor devices with either a p-n-p or n-p-n structure. There are two basic classifications of transistors: bipolar and field effect.

A Bipolar Junction Transistor (BJT) has three leads: a base, collector, and emitter. For an n-p-n BJT, a current flowing into the base causes the base-emitter junction to become forward biased, thus allowing current to flow from collector to emitter. A p-n-p BJT is similar except that holes provide the majority of conduction. A BJT operates on the principle that by increasing the base voltage the collector current increases even more, thus creating an amplifier.

A Field Effect Transitor (FET) has three leads: A drain, source, and gate. Current flows from source to drain through a channel. The conduction of current is due entirely to the flow of majority carriers through a conduction channel controlled by an electric field arising from a voltage applied between the gate and source terminals. FETs are also called unipolar transistors because current is conducted by charge carriers (electrons and holes) flowing through one type of semiconductor. This is in contrast to BJTs, where current passes through both p-type and n-type semiconductor materials in series.

There are various types of FETs, some of which are: the Junction FET (JFET), the MEtal Semiconductor FET (MESFET), the MOdulation Doped FET (MODFET), and the Metal Insulator Semiconductor FET (MISFET). A special type of MISFET is the Metal Oxide Semiconductor FET (MOSFET).

For a JFET, a voltage applied to the gate reverse biases the gate-to-channel junction, which results in a depletion region being formed in the channel. Since current cannot flow through the depletion region, the width of the channel can be effectively controlled, thus controlling the current. An amplifier is created because a small gate voltage change causes a corresponding much larger current change through the channel. A JFET can be made with either an n or a p type semiconductor material in its channel, just as a BJT can be made as either a n-p-n or a p-n-p device. The difference between p-channel and n-channel function is polarity reversal of all voltages and currents. Generally, n-channel devices are preferable for circuit applications.

A MODFET or HEMT (high mobility transistor) is composed of doped AlGaAs on undoped GaAs. Doping is changed from the A1GaAs layer to the GaAs layer so as to modulate (and optimize) charge carrier mobilities and velocities.

A MISFET operates on the same principal as a JFET but its physical construction varies slightly. The gate does not actually come in contact with the channel. Instead, there is a thin metal oxide between the two which causes a higher input resistance. A MISFET can be further classified as an enhancement or depletion type. The difference is that in a depletion type there is a physical channel, and in an enhancement type an electric field creates the channel. The MESFET results if the JFET junction is replaced by a Schottky junction.

Transistors are usually made from Si, (doped with boron and phosphorous) with GaAs expected to become more widely used in the future. Ge devices shall not be used in military applications without approval from the procuring activity.

b. ***Application*** -- Transistors are being used in a multitude of different applications. Basically, there are three regions where a transistor can operate, cutoff, active, and saturation. Analog amplifiers operate in the active region where there is an almost linear relationship between the gate voltage and the much larger collector-emitter or drain-source voltage. Transistors used in digital applications operate in the cutoff region where they are off, and the saturation region where they are on; and quickly switch through the active region.

BJTs were the first type of transistors mass produced and remain the most widely used. They are used in discrete circuits as well as in integrated circuits (ICs), both analog and digital. The device characteristics are understood well enough that one is able to design transistor circuits whose performance is predictable and quite insensitive to variations in device parameters.

MOSFETs and JFETs are easier to manufacture than BJTs. MOSFETs play a dominant role in digital IC design. P-channel devices (PMOS) and n-channel devices (NMOS) used in combination on the same integrated circuit are called Complementary-symmetry MOS (CMOS) circuitry. Microprocessors, logic, and memory circuits fabricated using Very Large Scale Integration (VLSI) techniques mostly employ MOSFETs. One disadvantage of MOSFETs, however, is they are very sensitive to static electricity due to their high input impedances.

JFETs are very useful in the design of special amplifier circuits, particularly those requiring very high input impedances. JFETs can also be combined with bipolar transistors to provide high performance linear circuits, which are called BIFETs.

The MESFET is a JFET structure using a Schottky junction in conjunction with GaAs. This FET is suitable for use in amplifiers and logic circuits intended for operation in the gigahertz range.

c. ***Reliability Information*** -- All transistors are sensitive to temperature changes, some more so than others. Also, all transistors exhibit a breakdown condition called avalanche breakdown.

These two effects impose limitations on the power-handling capability of a semiconductor device. A critical design parameter is junction temperature. At high case (ambient) temperatures, junction thermal considerations will therefore reduce the power that can be reliably operated at to values less than those imposed by secondary breakdown considerations. For most high-frequency circuit applications maximum junction temperatures of 150ºC should be observed; Gallium Arsenide (GaAs) digital devices should also observe this limitation.

BJTs are the least temperature sensitive, but because they are typically used in higher power applications the effect of temperature is still predominate. The collector to base current, with the emitter open (I_{CBO}), roughly doubles for every 10ºC rise in temperature. The common-emitter current gain (h_{FE}) also increases with temperature.

In a JFET temperature effects cause the gate current to increase with temperature, roughly doubling for every 10ºC increase in temperature. Also, the conductivity of the channel is dependent on temperature, which causes the gate-to-source voltage (V_{GS}) to change while the drain current is held constant. However, there is a particular value of drain current at which the temperature coefficient of V_{GS} is essentially zero, so a properly designed circuit can be made to express very little change with temperature.

In MOSFETs the threshold voltage (V_T), the drain current and β are all temperature sensitive. The magnitude of V_T often decreases by about 2.5 mV for each 1ºC rise in temperature (This variation is often not at a fixed rate, however, since V_T is actually a function of both temperature and doping density). also decreases, which causes a corresponding decrease in drain current as temperature increases.

All transistors exhibit a breakdown condition called the first breakdown or avalanche breakdown. When breakdown occurs, the result is a large increase in current with a negligible increase in voltage. The scientific explanation for this is that minority carriers crossing the depletion region gain sufficient kinetic energy to break covalent bonds in atoms. The carriers liberated by this process then have sufficient energy to break other bonds, and the process continues to repeat itself in an avalanche fashion.

The breakdown process differs slightly between BJTs and FETs. In FETs the breakdown voltage increases as the gate-source voltage increases, and in BJTs it decreases as the gate current increases. Breakdown can occur at either the emitter-base or the collector-base junction in a BJT. Breakdown of the collector-base junction is not destructive as long as the power dissipation in the device is kept within safe limits. However, emitter-base breakdown is detrimental in the sense thatis reduced.

In a MOSFET, breakdown occurs when the gate-to-source voltage exceeds about 100 V. However, because MOSFETs have very high input impedances, only a very low current is needed. A high voltage with a very low current is characteristic of static electricity, which is why MOSFETs are extremely static sensitive. When MOSFETs are used in ICs there should be some form of input protection, such as a clamping diode, that reduces (but normally will not eliminate), ESD sensitivity.

Transistors shall be derated as indicated in Table I-III, and Figure 300.1.

300.5 Thyristors

a. ***Description*** -- A thyristor is a group of semiconductor devices which have a P-N-P-N type structure and exhibit regenerative action. There are approximately 18 types of thyristors, but the most popular types are the Silicon Controlled Rectifier (SCR), the bidirectional triode thyristor (TRIAC), and the Gate Turn Off thyristor (GTO).

All thyristors are derived from the basic structure of an SCR. A SCR is similar in operation to a diode, except that it can be turned on during its forward blocking state by applying a positive voltage to its gate. A GTO differs in that it can be turned both on or off during forward blocking and conduction. Applying a positive voltage to the gate turns it on, and a negative voltage turns it off. The TRIAC is also similar to the SCR, except that it can conduct in either forward or reverse direction.

b. ***Applications*** -- Thyristors are used primarily in high power, high speed switching applications, such as converters, inverters, crowbar over voltage protection, and motor controllers. They are more efficient than transistors or mechanical relays when used in high power applications because of their high switching speed while the two p-n junctions allow for higher power operation. Presently, SCRs can switch up to 3000A at 2,000V.

Thyristors usually cannot operate at high frequencies for two reasons. First, they require a long recovery time after current is switched off; second, the maximum power dissipation occurs during switching and the resultant high temperature may cause component damage.

c. ***Reliability Information*** -- Thyristors have five design parameters requiring derating, plus three parameters which should be given attention in order to achieve a reliable design.

(1) ***Power*** -- Maximum steady state power shall be derated as shown in Figure 300.1. If other factors, such as high switching frequency, cause the thyristor junction temperature to rise above the maximum steady state value, the power shall be further derated.

(2) ***Forward Blocking Voltage*** -- Also called breakover voltage, determines the maximum voltage which can be blocked in the forward direction with the gate grounded. If exceeded, the device will usually turn on without damage to the thyristor, but there may be damage to other circuit elements. Forward blocking voltage shall be derated to no more than 50 percent of the specified maximum.

(3) ***Inverse Voltage*** -- Also called reverse breakover voltage or the maximum reverse voltage. It is the maximum voltage that can be reversed biased across a thyristor, and will destroy the device if exceeded. Maximum inverse voltage shall be derated to no more than 50 percent of the specified maximum.

(4) ***Forward Surge Current*** -- Thyristors can withstand a relatively high surge current, usually two to three times its forward continuous current. Surge current shall be derated to no more than 70 percent of the specified maximum.

(5) ***Turn-Off-Time*** -- Defined as the time needed for a thyristor to turn off before it can be turned on again. After a thyristor is turned off it cannot immediately be turned back on because of excess charge carriers within the device. A recombination of these carriers must first take place. Turn off times not less than 200 percent of device rating shall be used as derating criteria for this characteristic.

(6) ***Rate of Rise of Forward Current (di/dt)*** -- This parameter is not derated, but the thyristor can be damaged if the forward current is increased too rapidly causing localized excessive heat dissipation across the p-n junctions. To minimize this occurrence a pulse triggering technique called “hard firing” can be employed. With this technique, a relatively high amplitude short duration pulse is applied to the gate, followed by a smaller pulse. This allows conduction to take place across the entire cross-section of the device as fast as possible. There are also devices which have some type of “regenerative gate” which create high di/dt ratings.

(7) ***Rate of Rise of Forward Voltage (dv/dt)*** -- If the forward voltage is increased too rapidly the thyristor may turn on without the application of a gate signal

(self-triggering). This is because the internal capacitances of the thyristor junctions may draw enough charging current to induce triggering. Some thyristors have “shorted emitter” type construction which can increase the dv/dt capability. An effective method of preventing this type of malfunction is to install a resistor from gate to cathode and increase the gate driving voltage and current.

(8) ***Gate Triggering Voltage and Current*** -- This is the power necessary to drive the gate to cause triggering. There are two methods of triggering, pulse and continuous. To increase reliability, continuous gating should be used whenever possible. An exception to this rule is when a high rate of rise of foward current poses a problem. In this case, pulse triggering is more reliable. But in general, pulse triggering is less reliable but more energy efficient. A thyristor’s minimum pulse width varies with temperature, age, and load circuit characteristics. An anode -- cathode load with a large inductance requires a longer pulse width to be applied to the thyristor.

Thyristors have both a minimum and maximum triggering voltage and current. Applying a value above the maximum can destroy the device. Applying a value below the minimum prevents the thyristor from triggering, Also, the gating requirements usually decrease at high temperature, making extraneous signals on the gating lines more dangerous at high temperatures.

300.6 Fiber Optic Systems

The use of fiber optic systems in military applications is steadily increasing. This is because optical signals are relatively immune to an Electromagnetic Pulse (EMP) and do not produce any electromagnetic radiation. A fiber optic system is composed of three parts: photoemitters, photodetectors, and optical fibers.

300.6.1 Photoemitters

a. ***Description*** -- Photoemitters are devices which convert electrical signals into light. Short wavelength devices are made from a GaAs substrate on which a layer of GaAs alloyed with aluminum is grown, giving AlGaAs. Long wavelength devices are composed of Indium-GaAs-Phosphide (InGaAsP) grown on a substrate of Indium Phosphide (InP). There are four basic types of photoemitters: Light Emitting Diodes (LEDs), Surface-emitting LEDs (SLEDs), Edge-emitting LEDs (ELEDs), and Laser diodes.

A LED produces light by electron and hole migration into the active layer where they recombine to emit light. SLEDs and ELEDs work by the same principal except that they have confining layers. The confining layers confine the light in the active layer, forcing it to be emitted in a given direction with a decreased spectral width.

A Laser diode has reflective end facets which act as mirrors. The light is reflected back and forth and amplified. Above a threshold current, when the voltage exceeds the bandgap energy, the diode begins to “Lase”. Laser diodes have very narrow spectral widths, 3nm, and a high power output of about 1 mW. Currently, research is being done to make laser diodes with variable frequencies, allowing lightwaves to be heterdyned, substantially increasing their bit rates.

b. ***Application*** -- Photoemitter applications depend on the spectral width needed. LEDs have the widest spectral width, then SLEDs, ELEDs, and finally laser diodes. For analog systems LEDs may be more desirable because they lack a nonlinear threshold region. For digital links, a laser diode is more desirable because it can be modulated faster (500 MHz bandwidth). Between the light emitting and lasing states, a laser diode can be made to amplify the intensity of light incident from an incoming fiber. In this way it can be used as a photodetector and photoemitter at the same time, thereby reducing the number of parts in a repeater. Also, a long wavelength photoemitter can be modulated faster than a short wavelength device, thereby increasing its bit rate capability. However, long wavelength devices also require higher currents which increase power dissipation.

c. ***Reliability Information*** -- Since photoemitters are a type of opto-electronic semiconductor device, they shall be derated as described in Section 300.3. Some special considerations should be given to photoemitters in fiber-optic systems. It is desirable to emit as much power as possible into the fiber in order to increase its range and decrease the need for a high sensitivity photodetector. However, increasing power tends to decrease reliability, especially in laser diodes. A laser diode is more sensitive to changes in ambient temperature than a LED. It requires temperature monitoring and more sophisticated drive circuitry to control its stability against variations due to temperature and aging effects. Also, long-wavelength devices are more sensitive to temperature than short-wavelength devices. As the temperature of a laser diode increases, the current necessary for it to reach its lasing threshold increases. This increase is typically 20% for short wavelength devices, and 100% for long wavelength devices, between 25_ and 60ºC. At a high enough temperature a laser diode will spontaneously become an LED.

As the temperature increases the optical power decreases. For a LED, the optical power decreases by .5% for each 1ºC rise in temperature. For a long wavelength device the change is 1.5%/ºC. The peak wavelength of a photoemitter also changes with temperature. It changes by .25 nm/ºC for a short wavelength device, and .5 nm/ºC for a long wavelength device. This change is a more serious problem in laser diodes because of the narrower spectral width. As the peak wavelength changes the optical fiber's loss changes, which in turn changes the optical energy at the receiver.

300.6.2 Photodetectors

a. ***Description*** -- Photodetectors are devices which convert optical energy into electrical energy. There are many types of devices, but the three most popular are the photoconductor, the P-I-N photodiode and the avalanche photodiode. Short wavelength devices are made principally from silicon, while long wavelength devices are made from a variety of elements, including germanium as well as alloys from groups III and V of the periodic table.

The P-I-N photodiode derives its name from its three semiconductor layers. The i being an intrinsic or lightly doped region, and the p and n being semiconductor dopant layers. When the P-I-N photodiode is reverse biased, photons that are captured in the depletion layer create electron-hole pairs which generate a leakage current. This leakage reverse bias current is directly related to light intensity.

An avalanche photodiode (APD) works on the same principal with the exception that a higher reverse-bias voltage is applied. This causes more electron-hole pairs to be generated when photons strike the device. An avalanche multiplication takes place which is, in effect, a self amplifying process. An APD therefore has more gain than a P-I-N photodiode.

A photoconductor operates by using a material that increases its conductivity when it is illuminated. Present photoconductors utilize Type III-V compounds, such as Indium Phosphide (InP) and Indium GaAs (InGaAs). In the absence of light a photodetector is a simple resistor, and applied light causes a decrease in this resistance.

Research is being focused on the development of other types of photodetectors, including photo field effect transistors, phototransistors, reversed biased light emitting diodes, and a P-N-P-N detector emitter combination. Currently, these devices are not being used in any major systems but they may become widely used in future design applications.

b. ***Applications*** -- The P-I-N photodiode is the most popular photodetector. A P-I-N photodiode has the advantage of lower power requirements, and a response time (.1 to 10ns) roughly twice as fast as an avalanche photodiode. Its major disadvantage, however, is its absence of a gain mechanism. The P-I-N photodiode may require a significant amount of external circuitry in order to amplify its signal. In order to minimize the amplifying circuitry, P-I-N photodiodes are often combined with Field Effect Transistors (FETs) making a P-I-N/FET detector. The P-I-N photodiode is best suited for high speed, short distance applications when sensitivity is not critical.

An avalanche photodiode has the advantage of an internal gain greater than a hundred, about a 10db signal-to-noise ratio improvement, and a 5 to 7db improved signal sensitivity over a P-I-N photodiode or a photoconductor. But they are, in general, more difficult to use. An avalanche photodiode is more sensitive to temperature. In order to run at a constant gain some form of temperature compensation is required. Also, the leakage current should be kept at least an order of magnitude lower than the current generated by the optical signal to maximize sensitivity and signal-to-noise ratio.

Photoconductors have the inherent problem of excess noise. This arises from the lack of a p-n junction which means that there is always current flowing through it, regardless of the incident light energy. This current generates randomly fluxuating background current known as the Johnson noise current. Photoconductors have relatively high gains, but the gain is usually insufficient to offset the noise. They also have relatively low bandwidths, about 100 MHz for a fast device compared to 10GHz for a fast P-I-N photodiode.

Photodetector sensitivity decreases with increasing wavelength. A short wavelength photodetector is made from silicon, which has a bandgap energy of 1.1 electron volts. This causes its sensitivity to decrease to zero at a 1.1 micrometer wavelength. Long wavelength devices are made from materials which have greater sensitivities at longer wavelengths, but they also have dark currents (0.01 -- 0.1 A) which are too large for many applications. Dark current is leakage current present with no light applied to the detector.

c. ***Reliability Information*** -- Avalanche photodiodes and P-I-N photodiodes shall have power derated as shown in Figure 300.1. From a reliability standpoint, a P-I-N/FET detector is the preferred device. An avalanche photodiode requires 200 to 500 volts to operate while a P-I-N/FET detector operates at around 30 volts. Higher voltages make a photodiode more susceptible to voltage-accelerated failure mechanisms, such as surface charge contamination and electrolytic corrosion reactions.

The P-I-N photodiode and P-I-N/FET detector have an inherent problem of very shallow p-diffusion layers and a very thin oxide, which allow for sufficient light penetration. However, this also causes the device to be more susceptible to ionic contaminates. The reverse biased voltage causes ionic drift and localized charge concentrations. This manifests itself through degraded electrical parameters, such as increased leakage currents.

300.6.3 Optical Cables

a. ***Description*** -- Optical Fibers are composed of a transparent core surrounded by a transparent, depressed-index cladding which has a slightly lower index of refraction. The core allows light to travel down its length, while the cladding acts as a mirror, confining the light within the fiber. Most optical fibers used today are silica fibers. Their cores are made from silica (SiO_2), doped with germania (GeO_2), and possibly phosphorus pentoxide (P_2O_5), and the cladding is made from pure silica doped with boron oxide (B_2O_5) or fluorine (F). Research is being done using lower loss materials such as germanium.

There are two types of fibers: multimode and single-mode. Their primary difference is that single-mode fibers are only about 8.5 micrometers in diameter, while multimode fibers have a 50 micrometer diameter.

b. ***Application*** -- Basically, an optical fiber is much like an electrical wire, but instead of conducting electrical energy, it conducts optical energy. It connects a photoemitter at one end of the fiber, to a photodetector at the other. Optical fibers are extremely transparent but still have small losses. These losses vary with wavelength, giving a fiber a very limited bandwidth, shown in Figure 300.3. It is desirable to operate the photoemitters and photodetectors at a peak wavelength corresponding the lowest attenuation points of the optical fiber. The absolute lowest attenuation point occurs at 1.55 micrometers, with an attenuation of .15 to .80 db/km. Another low point occurs at 1.3 micrometers, where it is .3 to 1 db/km. Long wavelength fiber-optics attempt to operate at these two wavelengths. Short wavelength components operate at around .85 micrometers, where the attenuation is 2.5 to 3 db/km. Therefore it would be much more efficient to use a fiber at longer wavelengths. The problem however, is that at present it is more difficult to operate photoemitters and photodetectors at these longer wavelengths.

Losses in optical cables occur from three sources: Rayleigh Scattering, Chromatic dispersion, and multimode distortion. Impurities within the fiber were once a problem, but have since been almost totally eliminated.

Rayleigh scattering is the principal source of attenuation. It decreases as the inverse fourth power of the wavelength. It is caused by intrinsic non-homogeneous arrangements of molecules in the material. Very little can be done to prevent this because it arises from the fiber's material properties causing slightly different wavelengths to travel down the fiber at different speeds. This is the same phenomenon that allows a prism to split light into different colors.

Chromatic dispersion comes into play at high bit rates. It effectively "spreads out" the pulse, setting an upper frequency limit. Like Rayleigh scattering, it decreases with increasing wavelength.

Multimode distortion occurs because not all modes of light travel the same distance down a fiber. Some travel straight down while others are continually reflected off the surfaces. This spreads out the pulse, setting a maximum frequency limit for a given length of cable. This problem can be solved by the use of single-mode fibers. As the name implies, this type of cable only allows a single mode of light to exist within the cable.

Of the two types of fiber-optic cable, a single-mode cable is capable of transmitting light further than a multimode cable. Its disadvantage is that it is so thin that it is extremely difficult to splice the fibers together and couple the photoemitters and photodetectors to the fiber. Single-mode fibers are also more sensitive to small bends in the cable.

c. ***Reliability Information*** -- Optical fibers are a relatively reliable component in a fiber optic system. Since there is no current flow through the fiber, the common voltage and current accelerated failure mechanisms are not a problem. Also, glass is relatively immune to the same chemicals and ionic contaminates which are detrimental to semiconductor devices. In the event of failure occurrence it is usually catastrophic, resulting from a fiber break.

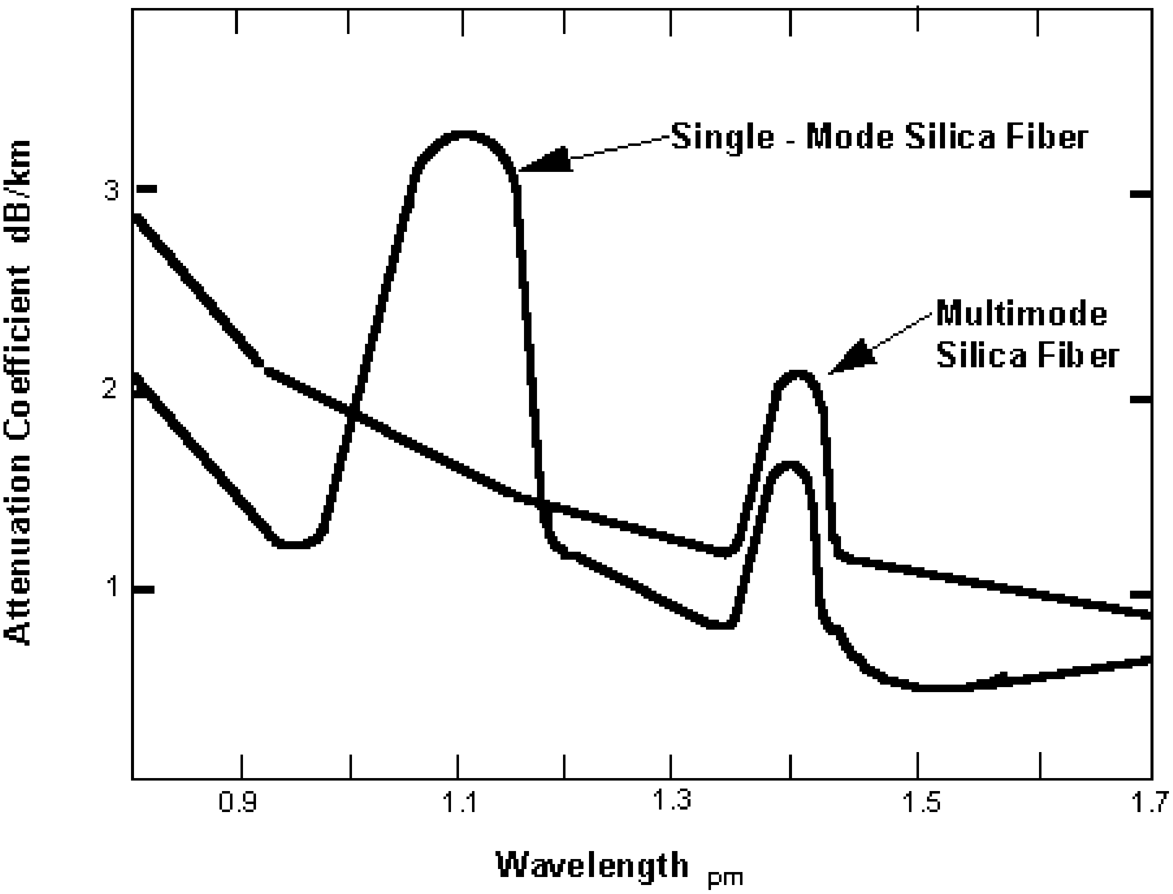


Figure 300.3 -- Loss Spectra of Optical Fibers

A fiber by itself is very weak. It contains many small weak spots called microcracks, which lower the fibers tensile strength. It has been shown that moisture will also weaken the fiber. To increase fiber reliability, it is usually coated with a plastic layer to increase its strength, and protect it from moisture and other environmental factors. Fibers can also be combined with cables to increase strength.

A second failure mode is increased attenuation caused by temperature fluctuations, radiation and/or microbending. Temperature fluctuations cause shifts in the fibers absorption band. Microbending is optical energy loss around sharp bends in the cable. An excellent solution to microbending is to use cables with a hard surface coating.

300.7 Microwave Devices

Microwave devices are diodes and transistors which can operate at microwave frequencies. Microwave diodes are divided into five categories: varactors, p-i-n diodes, tunnel diodes, transferred electron devices, and avalanche transit time devices. The latter three can be used at microwave frequencies by the utilization of their negative resistances. Varactors can be used because of their variable capacitances and p-i-n diodes because of their intrinsic semiconductor layer.

Tunnel diodes, transferred electron devices, and avalanche transit time devices differ in the way in which they are biased. Tunnel diodes have a forward biased p-n junction, transferred electron devices have no p-n junction and operate simply by the application of a d-c voltage to a bulk semiconductor, and avalanche transit-time devices have a reversed biased p-n junction. Microwave devices shall have power derated as shown in Figure 300.1.

300.7.1 Varactors

a. ***Description*** -- A varactor is a type of diode which can be used at microwave frequencies by utilization of its voltage dependent capacitance. A varactor is normally operated in the reversed biased mode. In this mode the simplified equivalent circuit is a junction capacitance in parallel with a junction resistance, and in series with a resistor. At low frequencies the junction capacitance is low, which allows the varactor to behave like a regular diode. However, at high frequencies the capacitance is high enough to consider the junction resistance, which is normally about 10M, to be negligible. The non-linear voltage dependent capacitance can then be considered for use as a circuit element.

b. ***Application*** -- A varactor can be used in three substantially different applications.

First, it can be used in a circuit as a modulator. Two inputs are applied to the circuit at two different frequencies, known as signal and pump frequencies. The varactor then multiplies the two inputs, producing a third frequency called the idler frequency.

Second, it can be used as a harmonic generator by the utilization of its non-linear characteristics. A sine wave is applied at one frequency and harmonics are generated at whole number multiples of this fundamental. Filters are then used to filter out all but the desired harmonic. These circuits are commonly called frequency doublers or triplers when used for these purposes.

The third application of a varactor is as a parametric amplifier. Signal, pump, and idler frequencies are again used. A parametric amplifier amplifies by the utilization of its input negative restance. The voltage reflection coefficient is larger than unity so power gains can be realized.

To choose a varactor for a particular application the following factors should be used:

(1) A capacitive impedance of the same order as the circulator

(2) For minimum noise a dynamic quality factor, Q, as high as possible

(3) A self-resonant frequency as high as possible

(4) For broadband amplifiers, a capacitance modulation factor as high as possible

(5) For cooled amplifiers, varactor characteristics should remain reasonable constant from room temperature to cryogenic temperatures

c. ***Reliability Information*** -- As a varactor ages its noise increases. Most noise occurs from thermal sources. To minimize thermal noise, varactors are often cooled to extremely low temperatures with liquid-nitrogen or liquid-helium. However, even at low temperatures plasma noise and shot noise are still present. Varactors made from GaAs are less susceptible to noise than silicon devices. Excess noise temperature due to shot noise is about 3_K/mA for GaAs and 25_K/mA for silicon. At extremely low temperatures the quality of a varactor seems to make little difference in noise generation. However, poorer quality varactors exhibit higher heat dissipation, which makes it more difficult to keep the varactor at a low temperature.

300.7.2 P-I-N Diode

a. ***Description*** -- A p-i-n diode consists of three semiconductor layers. Heavily doped p and n layers separated by the i layer, an intrinsic, or highly resistive layer. The i layer is not truly intrinsic, but actually doped slightly with p or n materials.

At low frequencies a p-i-n diode can be used as a diode or photodetector. However, at high frequencies internal device characteristics allow its resistance to be controlled by its d-c biased voltage.

b. ***Application*** -- A p-i-n diode has three basic applications: as a microwave switch, microwave detecter, or a variable attenuator. When using a P-I-N diode two useful parameters are the power-band product (the product of power and speed), and the gain-band product **(**the product of gain and speed**)**.

(1) ***Microwave Switch*** -- A p-i-n diode, like a common rectifier diode appears as a large impedance under reverse bias and a small impedance under forward bias. For switching applications, several diodes are connected in parallel with a common output, and different inputs from several different microwave channels. An external voltage source provides the biasing to each diode, switching on one diode at a time to the output, effectively switching on each channel. This process can also be done in reverse, switching one input to several outputs. A P-I-N diode is able to switch relatively large amounts of power with very little heat dissipation because most losses are second order effects.

(2) ***Microwave Detector*** -- A detector is a special case of a microwave switch. It is used in applications where large transmitters time share the same antenna with low-level receiving pulses. A diode must be used that is capable of carrying high power in one direction and have low noise in the other. To achieve this a p-i-n switch is driven with considerable more voltage and current than would otherwise be needed. In this way, gain is sacrificed at the expense of high speed.

(3) ***Variable Attenuators*** -- At microwave frequencies p-i-n diodes exhibit the property of behaving much like a variable resistor. Its resistance is almost linearly dependent

on its forward current. This property can be utilized to keep the output power relatively constant, thereby creating an attenuator.

300.7.3 Tunnel Diodes

a. ***Description*** -- A tunnel diode is a highly doped diode which has a very thin depletion-layer barrier at its p-n junction. This narrow barrier, along with the quantum tunneling of electrons through the barrier, allows the tunnel diode (sometimes known as the Esaki diode) to display negative resistance characteristics between peak and valley currents on the device I-V curve. The equivalent circuit of a tunnel diode is a negative resistance (about -30 ohm) in parallel with a capacitance (about 20pf).

Advantages of tunnel diodes include low cost, light weight, high speed, and low noise. A major disadvantage is severe output power limitations. The maximum voltage which can be applied must be below the bandgap voltage, which is only 1.40 V for GaAs. Tunnel diodes also have very low efficiencies, typically about 2 percent.

b. ***Applications*** -- Tunnel diodes are used in microwave applications because of their high oscillation frequencies. They can be used in two basic configurations: either parallel or series loading.

Parallel loading is used to produce microwave oscillators. A load resistance in parallel with the tunnel diode is allowed to approach the magnitude of the negative resistance of the diode. This produces an unstable circuit which will oscillate at microwave frequencies.

Series loading is used to produce microwave amplifiers. As the name suggests, a load resistance is placed in series with the tunnel diode. By allowing this load resistance to approach the negative resistance of the diode, a negative resistance amplifier is created.

c. ***Reliability Information*** -- In general, more heavily doped a diode is, the faster it fails. The fastest deterioration occurs when the diode is statically biased in the injection part of the characteristics at approximately twice the peak current (or higher).

Deterioration in tunnel diodes most commonly takes the form of a decreased peak current, increased injection current, and a decreased junction capacitance with time. Tunnel diodes deteriorate differently than most other semiconductor devices. Chemical and physical reactions occur within the diode and proceed until the device fails. That is, their failure rate over time more closely approximates that of a mechanical device rather than the “bathtub curve” for electrical devices.

300.7.4 Transferred Electron Devices

a. ***Characteristics*** -- Transferred Electron Devices (TEDs) are not true diodes because they have no p-n junctions. Instead, they utilize the bulk negative resistance property of uniform semiconductors. A TED’s oscillation frequency is a function of the load and the natural frequency of the circuit. They are used for many of the same applications as tunnel diodes.

TEDs are fabricated from compound semiconductors such as gallium arsenide (GaAs), indium phosphite (InP) or cadmium telluride (CdTe). There are four types of TEDs; the Gunn-effect diode, the limited space-charge accumulation (LSA) diode, CdTe diodes, and InP diodes.

b. ***Application*** -- A TED is used in two different applications, either as a microwave oscillator or a microwave amplifier.

A microwave oscillator is created by applying a DC voltage to the device, creating an electric field. If the field is greater than a threshold level the device becomes unstable and pulsed current oscillation occurs.

A microwave amplifier is created by applying an RF signal to a microwave oscillator. The microwave oscillator will amplify at nearby frequencies to its oscillating frequency. However, output power is limited and maximum efficiencies of only 3 percent are possible.

300.7.5 Avalanche Transit Time Devices

a. ***Description*** -- Avalanche transit time devices utilize the effect of voltage breakdown across a reversed-biased p-n junction to produce a negative resistance at high frequencies. There are two principal modes that this diode is operated in.

The first is the impact ionization and transit time (IMPATT) mode, for which the IMPATT diode is named after. It has a typical dc-RF conversion efficiency of between 5 and 10 percent, and oscillation frequencies up to 100GHz. It consists of a n-p-i-p^+ or p-i-n-i-n^+ structure, where i refers to an intrinsic material. The most popular diodes which operate in this mode are the IMPATT and the Reld diodes.

The second mode of operation is the trapped plasma avalanche triggered transit (TRAPATT) mode, for which the TRAPATT diode is named. Its dc-RF conversion efficiency is from 20 to 60 percent, and it can operate up to several gigahertz. A TRAPATT device has a n-i-p-p^+ or p-i-n-n^+ structure.

Another type of diode which operates as an avalanche transit time device is the barrier injected transit time (BARITT) diode. This diode consists of a p-n-p, p-n-i-P, p-n-metal, or a metal-n-metal structure. It has the advantage of much less noise than the IMPATT devices, but its use is limited due to its narrow bandwidth and limited output power.

b. ***Application*** -- Avalanche transit time devices are the most powerful solid state source of high frequency power. They are used in a variety of applications, including local-oscillator sources and pumps for amplifiers.

The IMPATT diode has two fundamental parameters: a resonant and a cutoff frequency. The resonant frequency is defined as the frequency at which the imaginary part of the diodes admittance changes from inductive to capacitive. The cutoff frequency is typically above the resonant frequency. The dc-RF conversion efficiency of IMPATT diodes increases substantially as the ratio of the voltage drop in the drift zone to the voltage drop across the avalanche zone (V_D/V_k) is allowed to increase. One important drawback is the noise inherent in the IMPATT ionization process which can interfere with the signal in some frequency ranges.

The TRAPATT diode can be made from either a n-i-p-p$^+$ or a p-i-n-n$^+$ structure. In almost all applications the n-i-p-p$^+$ structure is preferred. it has superior performance characteristics relative to efficiency and power output because of a narrower avalanche region which lowers the delay time.

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Section 400 -- Microcircuits

400 Microcircuits

400.1 General Information

Standard microcircuits are those listed in MIL-STD-1562. These devices are a subset of those meeting the general requirements of MIL-M-38510 and the detailed requirements of MIL-M-38510 slash sheets.

Microcircuits, also known as Integrated Circuits (ICs), enable one to produce a large number of complete circuits on the same Silicon (Si) wafer. Each circuit may contain a large number of transistors, diodes, resistors and possibly some small capacitors, all interconnected by overlying thin aluminum (Al) lines, ending up at a small number of Al pads to which electrical connections from the outside are made.

The whole wafer is processed as a single unit. When the metallization interconnection is completed each circuit is electrically tested, marked if defective, and finally the wafer is separated into individual dies, each comprising a single circuit. From this point on each circuit requires individual (and costly) handling. Each good circuit die (rectangular chip of the original wafer) is bonded on to header with Gold (Au) or Aluminum (Al). Wires are bonded to the A1 pads on the die and to the header terminals, and the encapsulation is finished by sealing.

A semiconductor integrated circuit can be based on bipolar, MOS, or Shottky technology as shown in Figure 400.1. The steps in the processing of these three technologies differ in both number and sequence, and these three technologies are not usually designed into the same circuit (although this can be done by a more complex processing).

The circuits may also be classified according to their use: linear circuits for both small signal and low to high power use, and digital circuits for logic use.

The rapid development of IC technology, since its inception the early 1960s, stems from several important causes:

a. Increased complexity of electronic circuitry;

b. The reliability problems associated with complicated circuits of discrete parts and large numbers of interconnections;

c. The need for reduction in required operating power;

d. Physical size and weight constraints;

e. The economics of high cost discrete parts vs relatively low cost ICs;

f. The ability of IC approaches to provide innovative and more effective solutions to systems problems (e.g., circuit speed).

400.1.1 Large Scale Integration

Economic pressures to produce larger, more complex chips, aided by steady progress in reducing chip defects, have resulted in the production of large scale integrated (LSI) circuits. The principal technical distinctions between LSI and conventional ICs are the number of gates (control-of-state elements), and the use of multilevel interconnections for LSI. This permits the efficient interconnection of individual ICs on the same wafer to form very complex circuits. It also allows extensive circuit changes by changing only a single interconnection mask.

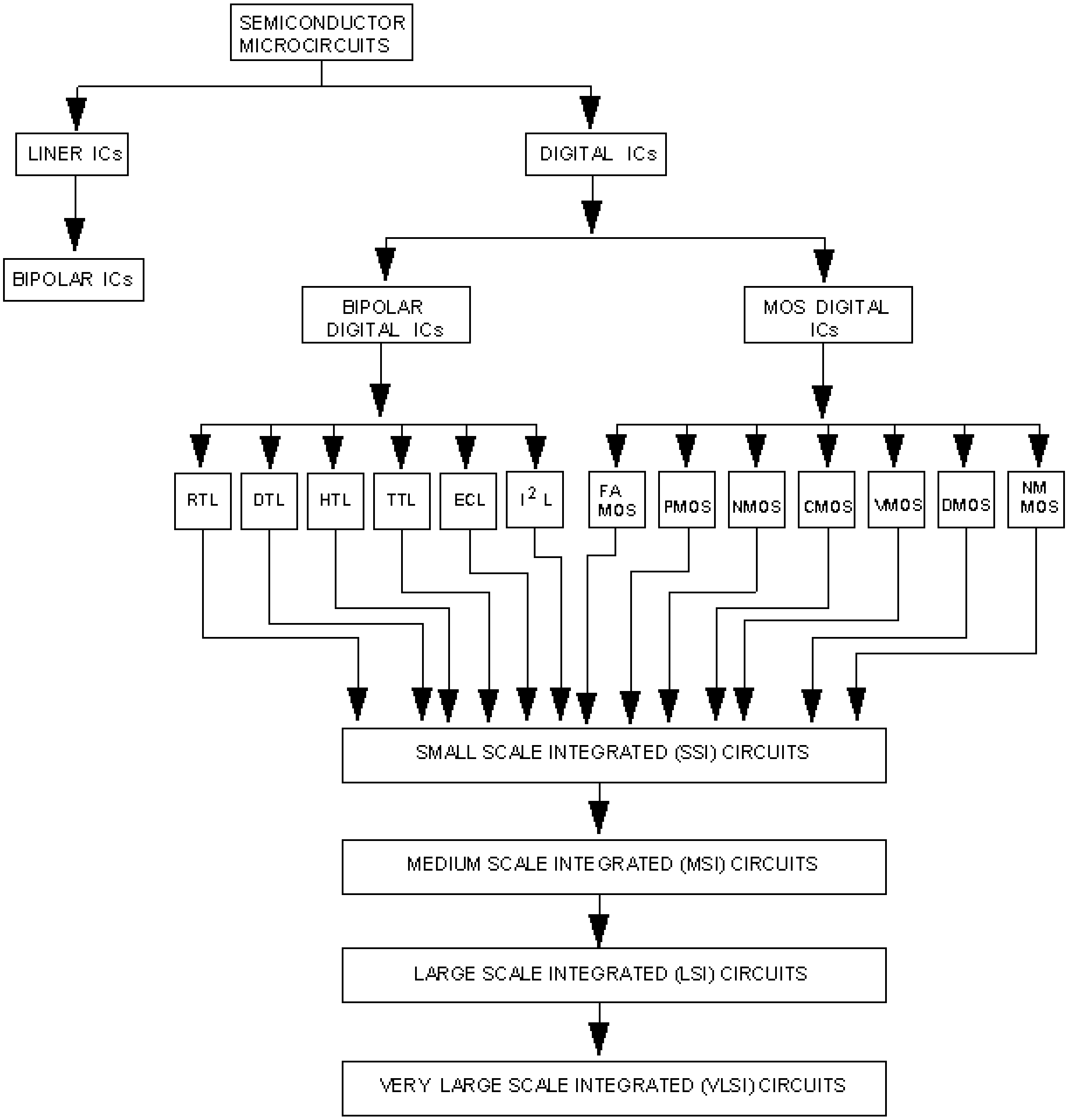

Figure 400.1 -- Semiconductor IC Schedule

Like other ICs, LSI chips require a mass (High Volume) market to be economically feasible. Thus, LSI manufacturers follow the IC strategy of mass producing general-purpose circuits and limited special purpose consumer circuits. LSI circuits offer an additional advantage -- programmability -- by which a standard circuit can be made to fit individual user special needs. Semiconductor memories and microprocessors are two widely used examples of programmable LSI circuits.

Read/write memories, often called Random-Access Memories (RAMs), are used for temporary storage of programs or data; these memories are volatile, i.e., data is lost when memory power is interrupted. Non-volatile semiconductor memories include Read-Only Memories (ROMs) and Programmable Read-Only Memories (PROMs). ROMs are usually mask-programmable, i.e., made to order by a semiconductor supplier using a custom interconnection mask. PROMs can be programmed electrically by the user or a programming service. These memories can be used not only for storage of data or programs, but also to replace logic gates.

Microprocessors provide the functional parts of a small general purpose computer in the form of a low cost LSI chip(s). Microprocessors are usually dedicated devices handling a variety of inputs and outputs in accordance with a fixed program. A microprocessor system design involves the programming of the processor's instruction ROMs as well as the physical interconnection to peripheral devices. Most processor programming is presently done in assembly language, although machine language and higher level languages are also used. The relatively high cost of programming makes the provision of higher language capability very probable in future microprocessor operations.

Custom designed LSI ICs provide the opportunity for maximum LSI performance to the user when a market for the product is large enough to recover design costs.

400.1.1.2 Digital Logic Families -- Characteristics

A logic family is a term which represents a method of constructing logic networks, and describes the types of components and the means by which these components are connected. The following discussion is intended to provide a brief summary of some widely used various logic schemes. Table 400-I presents a snapshot summary.

a. ***Resistor-Transistor Logic (RTL):*** Circuit input takes place across or through resistors, while circuit output is at output terminals of a transistor. This logic family is current-sourcing in that conventional current is from a driving gate to a driven gate or load (i.e.) the driving gate is a current source. The fan-out (number of like gates that can be driven) of RTL logic is usually 4 or 5, with fair operating speed, and with typical dead time delays (propagation times) of the order of 12 nsec.

b. ***Diode-Transistor Logic (DTL):*** Input signal events are applied to diode networks, with output taken from a transistor. This logic family is current-sinking since conventional current flow is from the driven gate into the driving gate. Fan-out is usually of the order of eight, or more.

c. ***High Threshold Logic (HTL):*** is essentially DTL logic, with an added functional requirement that input voltages must be high enough to exceed an operational threshold level. The main purpose is to achieve higher noise immunity to improper circuit triggering due to spurious signals. Slower gate response results in dead time delays of about 120 nsec; however, this allows for inherent high frequency noise signal filtering.

d. ***Transistor-Transistor Logic (TTL):*** This is presently the most often used integrated circuit logic. It can be thought of as saturation logic in that transistors are allowed to saturate in some operational situations. This logic family has no discrete component counterpart. This logic approach originates from design efforts to simplifying design and performance improvements of integrated circuit DTL/HTL. Several variations in TTL include High and Low Speed Schottky TTL (STTL, LSTTL, respectively), and advanced low-power Schottky TTL (ALSTTL, or ASL). The usual propagation or dead time delay with the above logic schemes varies from 3 to 20 nsec, with fan-out ranging from 8 to 20. TTL generally is current-sink logic, since in operation conventional current flow is from emitter lead of a driven gate into the collector of a portion of the driving gate. Further discussion of TTL is provided by paragraph 400.2.10.1.

e. ***Emitter-Coupled Logic (ECL):*** This can be considered as a major sub-set of TTL. ECL is a non-saturating logic scheme which avoids the speed-limiting effects of transistor charge-storage times by use of differential amplifiers within the integrated circuit. The emitter connections of the amplifiers allow for high impedance inputs within the circuit. ECL output allow for restoration of proper logic levels, with low output impedances for relatively higher fan-out. Further discussion of ECL is provided by paragraph 400.2.10.2.

f. ***Integrated-injection logic (I^2L):*** The I^2L logic scheme is essentially a unit input, multi-output inverter, with most of the output gate terminals connected to a common semiconductor region. Advantages include compact structure (high packing density), with reductions in gate areas. Variations include Schottky I^2L which enhances noise immunity and improves propagation time.

g. ***Complementary Metal Oxide Semiconductor (CMOS).*** This logic is based on MOS Field Effect Transistor (MOSFET) technology. CMOS gates use only MOSFETs as circuit components. An essential advantage of MOS technology is realization of a large array of various functions without the need for additional network components (e.g.) resistors, diodes, etc., are not required. CMOS cannot be actually classified as either current-sinking or current-sourcing logic since there is virtually no current flow between driving and driven gates due to inherently very high DC input resistances. This characteristic allows for high fan-out (dependent on switching frequency) as noted in Table 400-1. Packing densities can be very high, partially due to lack of need for resistors or diodes as circuit components. Further discussion of CMOS logic is provided by paragraph 400.2.10.3.

400.1.2 Production Fallout

Results of extensive screening tests indicate that while products of a well developed technology, such as simple TTL logic gates, had production fallout on the order of 1 percent of units tested, many newer and more complex devices had an alarmingly high fallout rate (5 percent to 19 percent). High device fallout rates become more significant when hundreds of devices are assembled into a completed assembly that is difficult and expensive to repair. Fallout rates of today's state-of-the-art devices will no doubt decrease and stabilize as their technologies mature. This is accounted for in the IC learning factor of MIL-HDBK-217 IC failure rate prediction method. In the meantime, it seems necessary for any serious user of complex ICs or LSI products to be prepared to perform comprehensive device screening in an attempt to find marginal devices to avoid high maintenance and repair/rework costs in the field.

400.1.3 Digital ICs

Digital ICs are the most commonly used ICs. They comprise the functional building blocks of logic and computer systems. Principal characteristics of some common digital logic families are summarized by 400.1.1.2 and Table 400-I. The comparisons given are for functions of the same complexity for units specified in the same operating temperature range. ICs of a given type are usually available in three specified temperature ranges, the most common being the industrial range of -25ºC to +85ºC and the military (MIL-M-38510) range of -55ºC to 125ºC as well as commercial (0ºC to +70ºC). The military temperature range ICs can cost several times more than the industrial range because of the need for more careful selection and testing. It is also worth noting that the most expensive IC lines (HTL, ECL, I^2L, CMOS) are also the least mature. Advantages and disadvantages of different families of digital ICs are summarized in Table 400-11.

400.1.4 Linear ICs

The linear line of integrated circuits can be indexed by functional applications such as:

- Voltage Regulator
- Voltage Reference
- Operational Amplifier
- Instrumentation Amplifier
- Voltage Comparator
- Analog Switch
- Sample and Hold Amplifier
- Analog to Digital Converter (A-D)
- Industrial/Automotive/Functional Blocks
- Audio, Radio and TV Devices
- Transistor Arrays

The absolute maximum ratings specified for these devices are similar to those of discrete transistors.

Table 400-I. -- Comparison of Some Major IC Logic Families

Parameter	**RTL**	**HTL**	**TTL**	**ECL**	**I^2L**	**CMOS**
Power Supply Voltage (+10%), Volt	3 to 3.6	15	5	-5.2	1.5 to 15	1.5 to 16
Gate delay, ns	10 to 25	80 to 100	3 to 15	0.5 to 2	10 to 50	10 to 50
Power Dissipation per gate, mw	2 to 15	50	10 to 25	25 to 50	0.05 approx.	50 nW freq. dep.
Fan out	4 to 5	10	10	10 to 25	1	5050 to100

Noise Immunity	Poor	Excellent	Very Good	Good	Fair	Very Good
Number of Functions	High	Low	High/Very High	High	Low	Medium
Cost Per Function	Getting Higher	Medium	Low/Medium	Medium	Low	Medium

Table 400-II. -- Advantages and Disadvantages of Different Families of Digital ICs

Advantages	**Disadvantages**	**Family**
RTL	1. Low supply voltage, low power dissipation 2. Relatively low noise generation 3. Most functions capable of implied “AND” connection	1. Low voltage-noise immunity 2. Low fanout 3. Obsolete (circuits will become scarcer and expensive)
DTL	1. Relatively low cost 2. Good fanout 3. Easily mixed with TTL	1. Relatively poor noise immunity despite large voltage-noise margins 2. Lower speed capabilities than other logic families 3. Declining market share -- poor rate of new function introduction
HTL	1. Best voltage and energy noise immunity 2. Largest logic swing 3. Interfaces well with electromechanical components. 4. Compatible with discrete power control devices such as Silicon Controlled Rectifiers (SCRs)	1. Relatively expensive logic form 2. Large gate delays 3. Relatively high power dissipation 4 Fewer functions available at present than other forms.
TTL	1. Highest speed of saturating logic forms 2. Good immunity to energy noise 3. Active pull-ups provide excellent drive capability 4.Good fanout 5. Wide and expanding variety of available functions 6. Readily available from many sources; medium speed TTL is very cost competitive with other logic forms	1. High voltage and current switching rates require careful layout to avoid cross talk 2. Internal current transients require well bypassed supplies 3. Active pull-up prevents implied “AND” connection in most forms 4. All forms except medium speed are relatively expensive

ECL	1. Highest speed logic available 2. Compatible with transmission line interconnection 3. Low levels of noise generation 4. Good fanout capability 5. Implied “OR” capability 6. Complementary outputs	1. Supply and logic levels require inter- facing circuits to saturating logic types 2. Power dissipation higher than some families 3. Low external noise immunity 4. High speed versions relatively high in cost
I^2L	1. Lowest (best) delay time-power product 2. Operates on very low supply currents per gate 3. Simple, high density structure promises 4. Low internal noise generation 5. Compatible with TTL drivers	1. Low external noise immunity 2. Not available in a broad range of functions 3. Unable to drive capacitive loads or transmission lines 4. Higher gate delays than TTL or ECL
MOS	1. Low power dissipation (especially CMOS 2. NMOS gives lowest cost per bit in large memories and shift registers 3. High device densities (especially single-channel) 4. Excellent fannout 5. CMOS has excellent noise immunity 6. Excellent for large scale integration 7. CMOS has very wide power supply range	1. Inherently slower than most bipolar and single channel dynamic logic 2. CMOS expensive, PMOS is becoming obsolete 3. Poor driving capability 4. Vulnerable to damage from static 5. High output impedance 6. Single channel low threshold circuits have relatively poor noise immunity 7. Requires insterfacing circuits to operate with bipolar families

400.2 Application Considerations

400.2.1 Use of a Minimum Number of Standard ICs

Standard ICs included in MIL-STD-1562 shall be used to the fullest extent practicable. Attempts should be made to minimize the required number of IC packages. A single MSI (medium scale integration, defined to have more than 12, but less than 100 gates per chip) can be used in place of a number of SSI (small scale integration, defined to have less than 12 gates (100 components)). Similarly, an LSI (large scale integration, containing in excess of 100 gates (1,000 components)) can be used in the system to replace several MSI chips. Thus a system should be defined in terms of standard MSI and LSI packages, if not VLSI (very large scale integration, with over 10,000 elements per chip) packages (see section 402). Discrete gates (SSI) should be used only for “interfaces” (also called the “glue”) as required between the subsystem ICs.

400.2.2 IC Package Type

There are four basic types of IC packages: Metal can, flat-packs, Dual-In-Line (DIP), and chip carrier. There is a further division in that the DIP packages are available in both ceramic and plastic. Special packages can be designed for specific applications, as the need arises. Approval for use of plastic and nonhermetically sealed ICs is required from the procuring activity.

In some cases, only one style is available for a particular IC. For example, where the IC operates at high power, and dissipates considerable heat, either the TO-3 or TO-5 metal can is required, because it permits the use of heat sinks or mounting directly on a metal chassis. Where there is a choice of package styles, where cost is a factor, or where a large volume of ICs is required, the DIP is generally the best choice. DIPs are ideally suited for mounting on printed circuit (PC) boards, since there is more spacing between the leads (typically 0.1 inch) than with other package types. During production, DIPs can be inserted (manually or automatically) into mounting holes on PC boards, and soldered by various mass production techniques.

The real weak spot in any IC package is at the seals where the leads enter the case or body. These seals are usually of glass or ceramic, if hermetically sealed, or plastic, if not, and can be easily broken exposing the chip and unplated metal inside the package. This can occur if the leads are bent or twisted during production or repair. Also, broken seals can result in moisture and other undesired elements entering the IC package. While this may not cause immediate failure, it will shorten the life of the IC. The exposed bare metal under the seal can also corrode, and affect the IC performance.

If reliability is the major factor, the ceramic flat-pack is generally the best choice. Ceramic ICs are hermetically sealed to protect the silicon chip. Flat-packs also have an excellent history of reliability. Flat-packs are smaller and lighter than DIPs, with all other factors being equal. Ceramic flat-packs are usually the choice for many military applications, except where high power is involved (there a metal can is preferred for heat dissipation).

400.2.3 Mounting and Connections

Once the package type has been selected, the IC must be mounted and electrically connected to other parts. The selection of a particular method of mounting and connection of ICs depends upon: the type of IC package, the equipment available for mounting and interconnection, the connection method used (soldering, welding, crimping, etc.), the size, shape and weight of the overall equipment package, the degree of reliability, the ease of replacement in the field, and the cost factor. The following sections summarize mounting and connection methods for the three basic package types.

400.2.3.1 Breadboard Mounting and Connection

During the breadboard stage of design, the IC packages can be mounted in commercially available sockets. This will eliminate soldering and unsoldering the leads during design and test. Such sockets are generally made of Teflon or similar material, and are usually designed for mounting on a PC board. Other IC sockets are designed for metal chassis mounting. In other cases, the IC can be soldered to the socket that is in the form of a plug-in PC card. The card can then be plugged into or out of the circuit during testing. (The use of sockets for production of the finished product, however, should not be done due to intermittent open circuit problems with such hardware.)

400.2.3.2 Ceramic Flat-Pack Mounting and Connection

There are a number of methods for making solder connections to flat packs. The notch in one end of the package which is used as a reference point to identify the lead numbering is generally nearest to lead number 1. Always consult the manufacturer's data regarding IC lead numbering.

Some common soldering techniques use in-line lead and pad arrangements. Although such arrangements simplify lead forming, they result in very close spacing between leads (typically .032 inches) and require the use of high precision production techniques in both board manufacture and the assembly of ICs on the board, particularly when leads must be inserted through holes in the PC board. Another disadvantage of the in-line arrangement is the limited space available for routing circuit conductors between adjacent solder pads.

Some of these disadvantages as referred to earlier can be overcome by the use of a staggered lead arrangement. In these staggered arrangements the lead holes and terminal pads for adjacent leads on the same edge of a flat package are offset by some convenient distance from the in-line axis. Although a staggered lead arrangement requires somewhat more PC board area per IC than the in-line arrangement, staggered leads provide several advantages:

(1) tolerances are far less critical;

(2) larger terminal pads can be used;

(3) more space is available for routing circuit conductors between adjacent terminal connections; and

(4) larger lead holes can be used to simplify lead insertion.

400.2.3.3 TO-5 Style Package Mounting and Connection

The most commonly used method for soldering TO-5 style packages is lead insertion into properly plated-through holes in the PC board with connection completed by wave soldering.

400.2.3.4 Dual-in-Line Package Mounting and Connection

Because the package configurations are very similar, the mounting arrangements and terminal sorting techniques used for these circuits are much the same as those used in the in-line method of paragraph 400.2.3.2 above, for the flat-pack ICs. The DIP terminal leads are larger than those of the flat-pack; the larger sized terminals are more rigid and more easily inserted in PCB or IC socket mounting holes.

Another significant feature of the DIP is the sharp step increase in width of the terminals near the package end. This step forms a shoulder upon which the package rests when mounted on the board. Thus, the DIP package is not mounted flush against the board and as a result, allows printed circuit wiring directly under the package. Also, convection cooling of the package is enhanced somewhat, and the component/circuit board can be easily removed if required.

400.2.3.5 Surface Mount Technology (SMT)

As of this issue of this manual, SMT is considered to be a relatively new technology, in the sense that internal industry elements or infrastructure, for provision of trained technical personnel, i.e., engineers, technicians, procurement functions, available vendors for components and materials, etc., are not as abundant as those for through-hole technology. As of this writing, industry or military standards for SMT are still evolving. Some examples of current documents are:

NAVSO P-3651	Thick film ceramic boards with leadless components
IPC-SM-782	Surface mount land patterns
IPC-SM-780	Electronic component packaging and interconnection with emphasis on surface mounting
IPC-SM-817	General requirements for surface mount adhesive

SMT may be thought of as an extension of hybrid circuit technology, which utilizes a mix of ICs and discrete active and passive circuit elements, all mounted on a single circuit board, either single- or double-side. The technology has evolved to the extent that surface mount assemblies can be separated into three configurations, in which production processes differ, and require different equipment for production:

Type I:	The assembly contains surface mounted components, single or double-sided.
Type II:	A combination of Type I and Type III (see below), although the Type II usually has no active components bottom mounted.
Type III:	The assembly contains only through-hole components on the top side and only discrete SMT components such as resistors, capacitors, inductors, and transistors which are glued to board bottom sides.

SMT provides advantages relative to both design and production/manufacturing:

a. Reduction in weight and size of complete board assemblies by use of “small outline integrated circuits” (SOIC) and small lead-pitch (lead spacing) packages (sometimes referred to as fine-pitch packages).

b. Enhancement of shock and vibration resistance due to decrease in component mass and shorter lead length.

c. Reduction in undesirable circuit operational side effects such as propagation (dead time) delay, parasitic signal generation (noise), with a corresponding reduction in the need for decoupling capacitors.

d. Reduced circuit board manufacturing costs, including material handling costs. Since hole drilling and sizing is reduced, trace routing is improved for those SMT designs not utilizing fine pitch of .25 inch and less. For those assemblies, the number of drilled holes can be the same or more than an equivalent through-hole printed wiring board.

The technology continues to evolve. Innovation, improvement, the onset of ultra-miniature design down into the molecular domain, as well as other drivers, both perceived as well as unforeseen, can be expected to play major roles in new system design and to remain at the cutting edge of electronic technology.

400.2.4 Considerations in Circuitboard Layout of ICs

Different parameters should be considered in layout of each type of IC. For example, most linear ICs have high gain, and are thus subject to oscillation if feedback is not controlled by circuit layout. On the other hand, digital ICs rarely oscillate due to low gain, but are subject to noise signals. Proper circuit layout can minimize the generation and pickup of such noise. The following paragraphs describe those circuit layout problems that IC users must face at one time or another.

400.2.4.1 Layout of Digital ICs

All logic circuits are subject to noise. Therefore, it is recommended that noise and grounding problems be considered from the very beginning of design layout.

Wherever DC distribution lines run an appreciable distance from the supply to a logic chassis (or a PC board), both lines (positive and negative) should be bypassed to ground with a capacitor, at the point at which the wires enter the chassis.

Use 1 to 10 F capacitors for power-line bypass. If the logic circuits operate at higher speeds (above 10 MHz), add a 0.01 F capacitor in parallel with each 1 to 10 F capacitor. Note that even though the system may operate at low speeds, there are higher frequency harmonics generated. These high frequency signals may produce noise on the power line and connecting wiring. If the digital ICs are particularly sensitive to noise, as is the case with the TTL logic form, use at least one additional bypass capacitor for each 12 IC packages.

The DC lines and ground return lines should have cross sections sufficiently large to minimize noise pickup and DC voltage drop. Unless otherwise recommended by the IC manufacturer, use AWG No.20 or larger wire for all digital IC power and ground lines.

Keep all leads as short as possible to minimize noise pick up. Typically, present day logic circuits operate at speeds high enough so that the propagation time through long wire or cable can be comparable to the delay time through a logic element.

The problem of noise can be minimized if ground planes are used, that is, if the circuit board has solid metal sides. Such ground planes surround the active elements on the board with a noise shield. If it is not practical to use boards with built-in ground planes, a wire should be run around the outside edge of the board with both ends of the wire connected to a common or "equipment" ground.

Do not run logic signal lines near a clock line for more than 7 inches because of the possibility of cross talk.

Some digital IC manufacturers specify that a resistor (typically 1 k) be connected between the gate input and the power supply (or ground, depending upon the type of logic), where long lines are involved. Always check the IC data sheet for such notes.

400.2.4.2 Circuit Layout of Linear ICs

The main problem with layout of linear ICs is undesired oscillation due to feedback. Since the ICs are physically small, the input and output terminals are close, creating ideal conditions for the occurrence of undesired feedback. To make matters worse, most linear ICs are capable of passing frequencies higher than those specified on the data sheet.

For example, an operational amplifier used in the audio range (i.e., up to 20 kHz with a power gain of 20 dB) could possibly pass a 10 MHz signal with some slight gain. This higher frequency signal could be a harmonic of signals in the normal operating range and, with sufficient gain, could feedback to the input and produce undesired oscillation. Therefore, always consider linear ICs as being RF, in laying out circuits, even though the IC is not rated for RF operation and the circuit is not normally operated at such frequencies. The use of a capacitor to bypass IC power supply terminals to ground will aid in providing a path for any RF.

Keep IC input and output leads as short as possible. Use shielded leads wherever practical. Use one common tie point near the IC for all grounds. Resonant circuits can also be formed by poor grounding or by ground loops in general.

ICs mounted on PC boards (particularly with ground planes) tend to oscillate less than instances in which conventional wiring is used. For that reason, an IC may oscillate in the breadboard stage, but not when mounted in final layout form.

Once all of the leads have been connected to an IC and power is applied, monitor all IC terminals for oscillation with an oscilloscope before signals are applied.

400.2.5 Power Dissipation in ICs

The maximum allowable power dissipation, "P_D" for an IC is a function of the temperature above which derating must occur "T_S", the maximum ambient temperature "T_A", and the thermal resistance from the semiconductor chip to ambient "θ_{JA}". The relationship is:

$$P_D = \frac{T_A - T_S}{\theta JA}$$

IC data sheets do not necessarily list all of these parameters. It is quite common to list only the maximum power dissipation for a given ambient temperature and a maximum power decrease for a given increase in temperature.

For example, a typical IC might show a maximum power dissipation of 110 mW at 25ºC, with a decreasing power rating of 1 mW/ºC for each degree above 25ºC. If this IC is operated at 100ºC, the maximum power dissipation would be: (100 mW -- (100ºC-25ºC)(1 mW/ºC)) = 25 mW.

In the absence of specific data sheet information, the following typical temperature characteristics can be applied to the basic IC package types:

a. Ceramic flat pack:

   Thermal resistance = 140ºC/W
   Maximum storage temperature = 175ºC
   Maximum ambient temperature = 125ºC

b. T0-5 style package:

   Thermal resistance = 140ºC/W
   Maximum storage temperature = 200ºC
   Maximum ambient temperature = 125ºC

c. Dual-in-Line (ceramic):

   Thermal resistance = 70ºC/W
   Maximum storage temperature = 175ºC
   Maximum ambient temperature = 125ºC

As previously stated, power ICs usually use either the TO-3 or TO-5 style package. The package is metal and is typically used with some type of heat sink (either an external heat sink or the metal chassis). The data sheets for power ICs usually list sufficient information to select the proper heat sink. Also, the data sheets or other literature often provide recommendations for mounting power ICs. Always follow the IC manufacturer’s recommendations. In the absence of such data and to make the reader more familiar with the terms used, the following sections summarize considerations for power ICs.

400.2.5.1 Power ICs

400.2.5.1.1 Maximum Power Dissipation

If the power supply voltages, input signals, output loads, and IC ambient temperature are at their recommended levels, the power dissipation will be well within the capabilities of the IC. With the possible exception of the data required to select or design heat sinks, the user need only follow the data sheet recommendations. The rated power decrease with increase in temperature must be considered in the determination of the allowable power dissipation (see the derating requirements).

400.2.5.1.2 Thermal Resistance

Thermal resistance can be defined as the increase in temperature of the semiconductor material (transistor junctions), relative to some reference, per unit power dissipated.

Power IC data sheets often specify thermal resistance at a given temperature. The IC characteristics can change with ambient temperature and with the variation in power dissipation. Most ICs incorporate circuits to compensate for temperature effects. In power ICs, thermal resistance is normally measured from the semiconductor chip (or pellet) to the case. This results in the term θ_{JC}.

400.2.5.1.3 Thermal Runaway

When current passes through a transistor junction, heat is generated. If this heat is not dissipated at the case, the junction temperature will increase. This temperature increase causes more current to flow through the junction, even though the voltage and other circuit values may remain constant. With a corresponding increase in current flow the junction temperature increases even further until the transistor burns out. This is known as thermal runaway.

Temperature compensation circuits have been developed by IC manufacturers; the most common approach places a diode in the reverse bias circuit for one or more transistors in the IC.

400.2.5.1.4 Operating ICs With and Without Heat Sinks

If a power IC is not mounted on a heat sink, the thermal resistance from case to ambient would be so large the allowable power dissipation would be minimal. In general 1 watt is the maximum power dissipation for an IC operating without a heat sink. At higher power dissipation levels it becomes impractical to increase the size of the case to make the case-to-ambient air thermal resistance term comparable to the junction-to-case term.

To properly design a heat sink for a given application, the thermal resistance of both the IC and heat sink must be known. Commercial fin-type heat sinks can be used with T0-5 style ICs. Such heat sinks are especially useful when breadboard ICs are mounted in Teflon sockets, which provide little thermal conduction to the chassis or PCB. (It should be noted, however, that production design should not use socket mounts.)

Commercial heat sinks are rated by the manufacturer in terms of thermal resistance, usually in °C/W. For example, if the heat sink temperature rises from 25°C to 100°C when 25 W are dissipated, the thermal resistance is 75/25 = 3. This would be listed on the data sheet as a $_{SA}$ of 3°C/W. With all other factors being equal, the heat sink with the lowest thermal resistance (°C/W) is best.

Practical heat sink considerations are as follows:

a. When ICs are to be mounted on heat sinks, some form of electrical insulation is usually required between the case and heat sink since most IC cases are not at electrical ground.

b. Because good electrical insulators usually are also good thermal insulators, it is difficult to provide electrical insulation without introducing some thermal resistance between case and heat sink. The best materials for this application are mica and beryllium oxide (Beryllia), with typical ºC/W ratings of 0.4 and 0.25, respectively.

c. The use of a zinc oxide filled silicon compound between the washer and chassis, together with a moderate amount of pressure from the top of the IC helps to decrease thermal resistance. If the IC is mounted within a fin-type heat sink, an insulated cap should be used between the case and heat sink.

d. When a washer is added between the IC case and heat sink a certain amount of capacitance is introduced. In general, this capacitance will have no effect on operation of ICs unless operating frequency is above 100 MHz. Rarely, if ever, do power ICs operate above the audio range. Thus, few such problems should be encountered.

400.2.5.2 Effects of Temperature Extremes on ICs

The effects of temperature extremes, either high or low, will vary with the type of IC involved, case style and fabrication techniques of the manufacturer. The following general rules can be applied to most ICs:

a. In some instances, the IC will fail to operate at temperature extremes, but will return to normal when the operating temperature is returned to the "normal" range.

b. In other cases, the IC will fail to operate properly once it has been subjected to a temperature extreme. In effect, the IC is destroyed once it is operated at an extremely high temperature primarily because of thermal runaway.

c. In general, high temperatures cause the IC characteristics to change. An increased operating temperature also produces increased leakage currents, increased sensitivity to noise, increased unbalance in balanced circuits, increased "switching spikes" or transient voltages for transistors in digital ICs, and an increase in burn-out.

d. If power supply voltages, input signals, output loads, and ambient temperatures specified on the data sheet are observed, there should be no danger of failure for any IC. However, as a final check, multiply the rated thermal resistance by the maximum device dissipation and add the ambient temperature. If the result is less than the maximum allowable temperature defined on the appropriate derating curve, the device application is acceptable.

e. When an IC is operated at its low temperature extreme, the IC is likely to "underperform". Usually at low temperatures, gain and power output will be different for operational amplifiers and other linear ICs; operating speed will be reduced for digital ICs; and the drive or output load capabilities of digital ICs will be reduced.

f. In no event should the IC be operated below the rated low storage temperature. As a general rule, the low storage temperature limit is 10ºC to 20ºC below the operating limit.

400.2.6 Power Supplies for ICs

All IC power supply voltages should be referenced to a common ground, which may or may not be earth or equipment ground.

As in the case of discrete transistors, manufacturers do not agree on power supply labeling for ICs. Some manufacturers use V+ to indicate the positive voltage and V- to indicate the negative voltage, whereas another manufacturer might use the symbols V_{EE} and V_{CC} to represent negative and positive respectively. Thus, the IC data sheet must be studied carefully before connecting any power source. Typically, digital IC power supplies must be kept within ± 5 to ± 10 percent, whereas linear ICs will generally operate satisfactorily with power sources of ± 20 percent. Power supply ripple and regulation are also important. Solid state power supplies with filtering and voltage regulation are recommended. Ripple and any other power supply noise must be kept below 1 percent for noise sensitive circuits. Proper sequencing of supply voltages should be observed; refer to the manufacturers specifications.

Proper value capacitors are used with power supply circuits to provide decoupling of the power supply (signal bypass). Usually, disc ceramic capacitors are used for this purpose. The capacitors should always be connected as close to the IC terminals as is practical, not at the power supply terminals. For linear IC power supply decoupling capacitors use capacitance values between .1µF and .001µF.

400.2.7 Determination of Current Required for Linear ICs

The specification sheets for linear ICs usually specify a nominal and possibly a maximum operating voltage, as well as a “total device dissipation”, which is defined as the DC power dissipated by the IC itself with output at zero and no load. The required current is obtained by dividing the power by the voltage.

400.2.8 Determination of Current Required for Digital ICs

Digital ICs operate with pulses. Thus, current is maximum in either of two states, but not in both states. Most digital IC data sheets list the current drain for the maximum condition. Manufacturers list I_{PDL}, the current drain when the logic signals are low, or I_{PDH}, the “high-state” current drain. If both I_{PDL} and I_{PDH} are listed, it is obvious that the higher of the two indicates the maximum current drain state. Thus current drains should be averaged to calculate power. The current requirements for digital ICs are also affected by the operating speed of the logic circuits and the type of loads into which the IC must operate.

A digital IC will require more current as the operating speed is increased. Generally, the data sheet will list a “nominal operating speed”, a “maximum operating speed”, and the current drain at the “nominal speed”. The IC should never be operated beyond the maximum speed limit. When operating between the nominal and maximum speeds, the additional current can be approximated by adding 0.5 to 1 mA for each 1 MHz of speed increase.

400.2.9 Application Data for Commonly Used Linear ICs

400.2.9.1 Operational Amplifiers (Op-amp)

The source of signal error in the op-amp is due to the non-ideal parameters of the device. However, in many applications, the difference between ideal and actual parameters are close to negligible in terms of overall performance. The two parameters affecting signal output error are: finite open-loop gain and finite input resistance. (The ideal characteristics are infinite open-loop gain and input resistance). These two non-ideal parameters produce: offset voltage at input; offset current at output; input noise; frequency instability and bandwidth limitations.

a. ***Offset Voltage Error*** -- In applications where a source of error due to input offset voltage is undesirable, select devices with minimum offset voltage characteristics and configure the circuit for offset voltage nulling.

b. ***Offset Current*** -- If use of an op-amp with high input resistance and low bias current is required then the FET input op-amp should be considered. FET input op-amp features initial (room temperature) bias currents in the 10^{-12} ampere region, however, they have relatively high positive temperature coefficients in terms of change in input bias current versus change in temperature. This characteristic must be considered.

c. ***Input Noise*** -- In choosing an op-amp, the requirement will often dictate a source resistance from which the amplifier must operate. This will dictate the noise performance specification of the device. In general, low input current amplifiers, such as FET input op-amps or low bias current bipolar type op-amps will have lower noise factor with impedances above 10 k. Below 10 ksource impedance, the bipolar input op-amp has the lower noise factor. Another consideration is that the noninverting configuration has only half the noise gain as the inverting configuration for equal signal gain, therefore, it offers a lower signal-to-noise ratio. In addition, optimum noise performance may be obtained by the use of transformer coupling.

d. ***Frequency Instability and Limited Bandwidth*** -- Frequency compensation and slew rate considerations are the most important for optimum ac performance in terms of stability. Frequency compensation is obtained by external circuitry or by selection of devices with internal compensation.

e. ***Latch-up*** -- Latch-up occurs most often in voltage follower stages where the output voltage swing is equal to the input, and the op-amp output is driven to high levels. Methods to eliminate this failure mode must be considered.

f. ***Output Short Circuit Protection*** -- Devices with limiting at the output should be considered in the design. If this protection is not internal to the chip, external protective circuitry must be provided.

g. ***Supply Voltage Protection*** -- Protection circuitry against damage to devices during reversal of power supply voltage or power supply over-voltage should be considered.

400.2.9.2 Voltage Regulators

Voltage regulators consist of a reference voltage and sense error amplifier and a pass power transistor in series with a load or in shunt with a load to control voltage across load. Regulation to within 0.01 percent can be achieved. When a specific degree of output voltage regulation must be provided, the various error sources that influence the total performance must be separated and analyzed. This includes those source errors as discussed in paragraph 400.2.9.1. Other error sources include temperature drift, wiring voltage drops, power supply induced noise, drift and quality of the reference source. Application considerations are as follows:

a. ***Voltage Drift Due to Temperature*** -- Temperature compensated devices should be considered to minimize errors due to changes of temperature above or below the designed optimum.

b. ***Offset Voltage Drift*** -- Circuitry can be provided to initially adjust offset voltage to minimize null offset voltage errors.

c. ***Wire Size*** -- One of the principal sources of error in high current and extremely close regulation tolerance is the wire size used between regulator terminal and load resistance. Wiring voltage drop must be considered.

d. ***Noise Characteristics*** -- Because of inherent noise characteristics of zener and reference diodes, filtering must be provided.

e. ***Input-Output Voltage Differential*** -- The input-output voltage differential should be limited such that proper voltage regulation is assured.

400.2.10 Application Data for Commonly Used Digital ICs

400.2.10.1 TTL Devices

The TTL microcircuit families provide general purpose logic with medium to high speed signal propagation, good noise immunity, and a high degree of economical logic flexibility. The switching speeds, especially associated with the very fast rise and fall of the circuits, are in the RF range and good high frequency circuit layout techniques have to be used.

Fanout capability is determined and specified by the device manufacturer. The voltage and current conditions needed for medium power TTL devices are normalized to a fanin or a fanout of a certain number of TTL loads. For applications requiring the device to drive more than the specified TTL load a buffer device should be used. Types of TTL devices are:

a. ***Standard*** -- Intended for use in implementing logic functions where speed and power requirements are not critical. This family offers a full spectrum of logic functions in various packages. Typical gate power dissipation is 10 mW with a typical propagation delay time of 10 ns. These devices exhibit a fanout of 10 when driving other standard TTL devices and are usually used to perform general purpose switching and logic functions.

b. ***Low Power*** -- Employed in logic design where low power dissipation is a primary concern. These devices have a typical gate power dissipation of 1 mW with a typical propagation delay time of 30 ns. Typically, these devices will drive only one standard TTL device but exhibit a fanout of 10 when driving other low power devices. Low power generates less heat and therefore allows for greater board densities. Lower current levels also introduce less noise and reduce constraints on power supplies.

c. ***High Speed*** -- Used to implement high speed logic functions in digital systems. These devices employ a Darlington output configuration to achieve a typical propagation delay time of 6 ns. The typical gate power dissipation is 23 mW. These devices can drive up to 12 standard TTL devices and exhibit a fanout of 10 when driving other high speed devices. These devices are used in high speed memories and central processor units.

d. ***Schottky*** -- Used when ultra-high speeds are desired. These devices employ shallow diffusions and smaller geometries which lowers internal capacitance to reduce delay time and sensitivity to temperature variation. Typical delay time is 3 ns and power dissipation is 19 mW per gate. However, this power dissipation increases with frequency. These devices can drive 12 standard TTL devices and up to 10 Schottky devices. Noise margin is typically 0.3 volt. A ground plane is recommended for interconnections over 6 inches long and twisted-pair lines for distances of 10 inches.

400.2.10.2 ECL Devices

The general application data for ECL microcircuits are the same as that for TTL type. The ECL type microcircuits are intended for use in digital systems requiring high switching speeds and moderate power dissipation. Typical propagation delay time is 2 ns and typical power dissipation is 25 mW. The logic levels (-0.9V and -1.7V) are not as easily detected as those of TTL devices. Intended for use in high speed systems such as central processors, memory controllers, peripheral equipment, instrumentation and digital communications. Typical DC fanout can approach 90; while AC fanout is usually limited to 5 due to circuit response-time consideration when driving ECL devices.

400.2.10.3 CMOS Devices

The Complementary Metal Oxide Semiconductor (CMOS) microcircuits provide a general purpose logic family with low power, medium propagation speeds, good noise immunity, and reasonable degree of logic flexibility.

The CMOS devices are intended for use in applications where low power is extremely desirable and high speeds are not essential. The typical power dissipation is 10 mW and increases with frequency. Typical delay time is 50 ns. A typical fanout for a CMOS gate is 50 CMOS loads or 1 TTL unit load. Noise immunity is typically 2.25 volts for CMOS compared to 0.4V for standard TTL devices when powered by a 5 volt supply. This makes these devices useful in high noise environments. These devices are highly tolerant of power supply variation and operate anywhere in the range of 3 to 15 volts. Characteristics are as follows:

a. ***Input Source*** -- The input requires a minimal current (typically 10 pico amps) voltage source in the low or high logic state. The voltage source has to be less than the device operating power supply voltage range.

b. ***Output Load*** -- The fanout or output loading factor is determined by the current or sink capability of the device or the number of logic gates that can be controlled. The output of CMOS digital microcircuits generally satisfies the input source requirements for other CMOS devices.

400.2.11 Electrostatic Discharge Susceptibility

Almost all integrated circuits are found to be susceptible to damage by electrostatic discharge. ESD handling precautions compatible with DOD-STD-1686 and DOD-HDBK-263 shall be observed, not only for individual ICs, but for assembled and mounted circuits as well.

401 MIL-M-38510, Microcircuits

401.1 Derating Requirements

When using linear microcircuits, power shall be derated according to the maximum allowable derating curve as shown in Figures 400.2, 400.3, 400.4, 400.5, 400.6 and 400.7. In those instances in which T_s may differ from the values provided (due to device composition or construction) the derating curves should be appropriately revised.

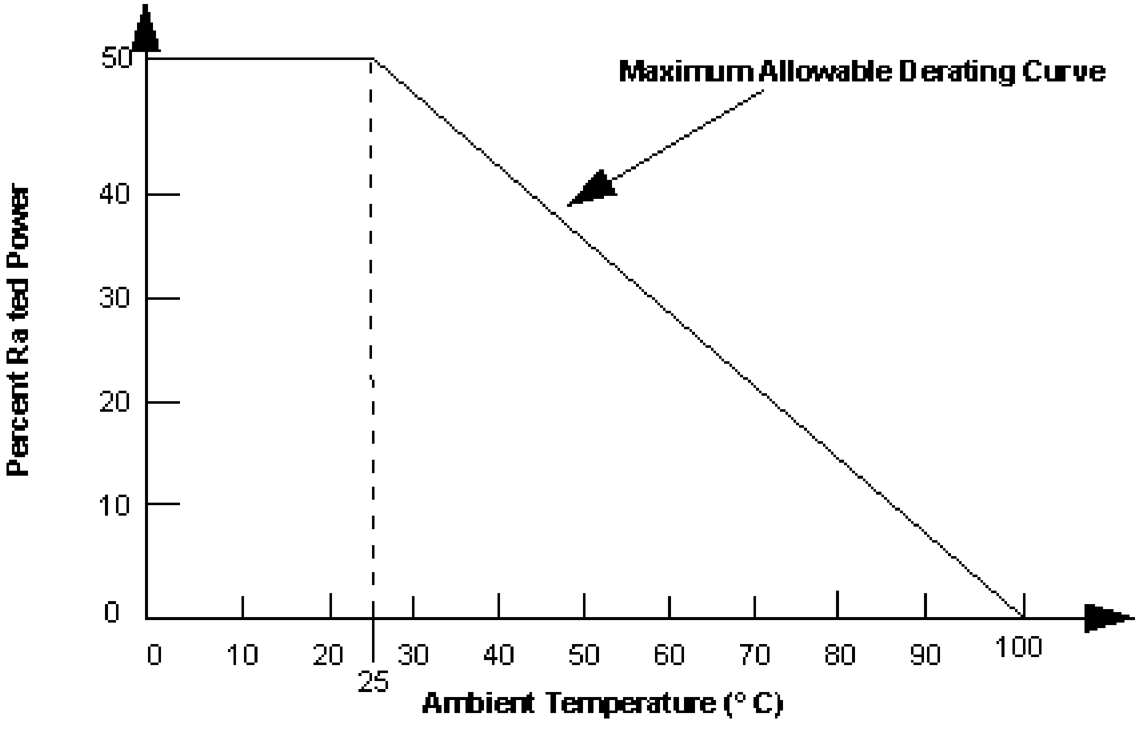

Figure 400.2 -- Derating Requirements for all Hermetically Sealed Microcircuits, Except Voltage Regulators, With T_S *= 25ºC*

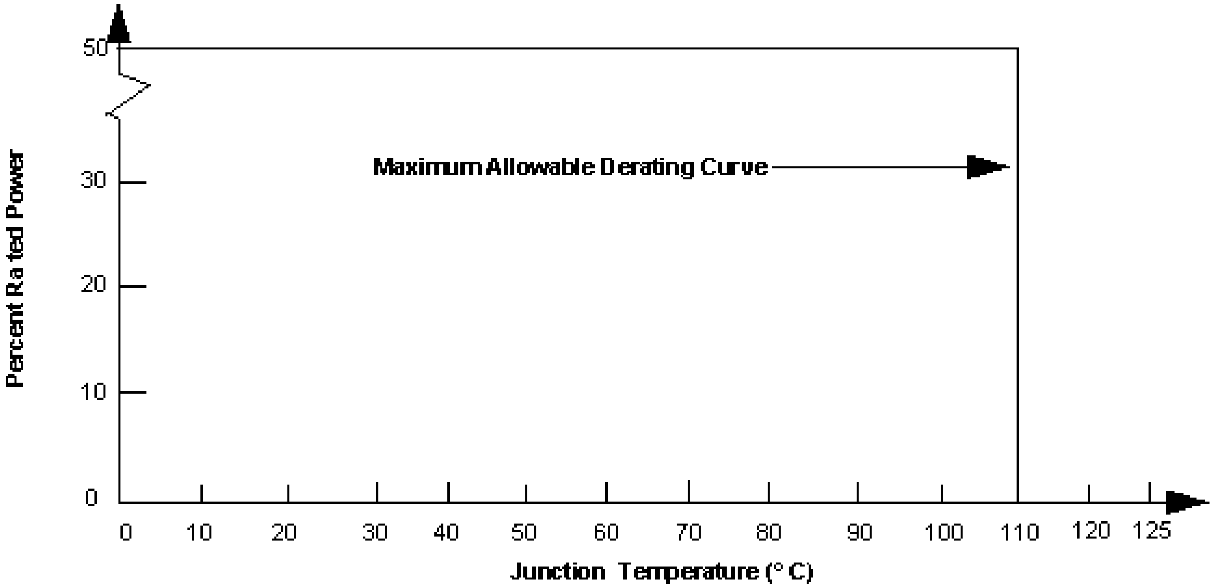

Figure 400.3 -- Derating Requirements for all Nonhermetically Sealed Microcircuits, Except Voltage Regulators, With T_S = 125ºC

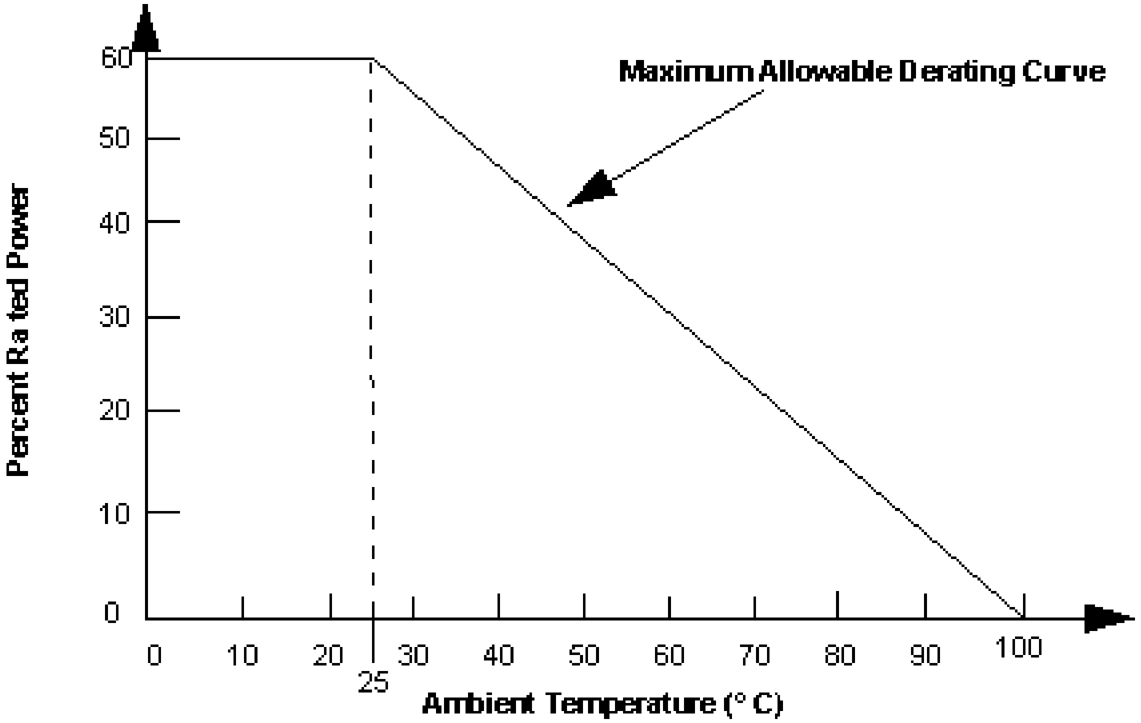

Figure 400.4 -- Derating Requirements for Hermetically Sealed Voltage Regulators With T_S = 25ºC

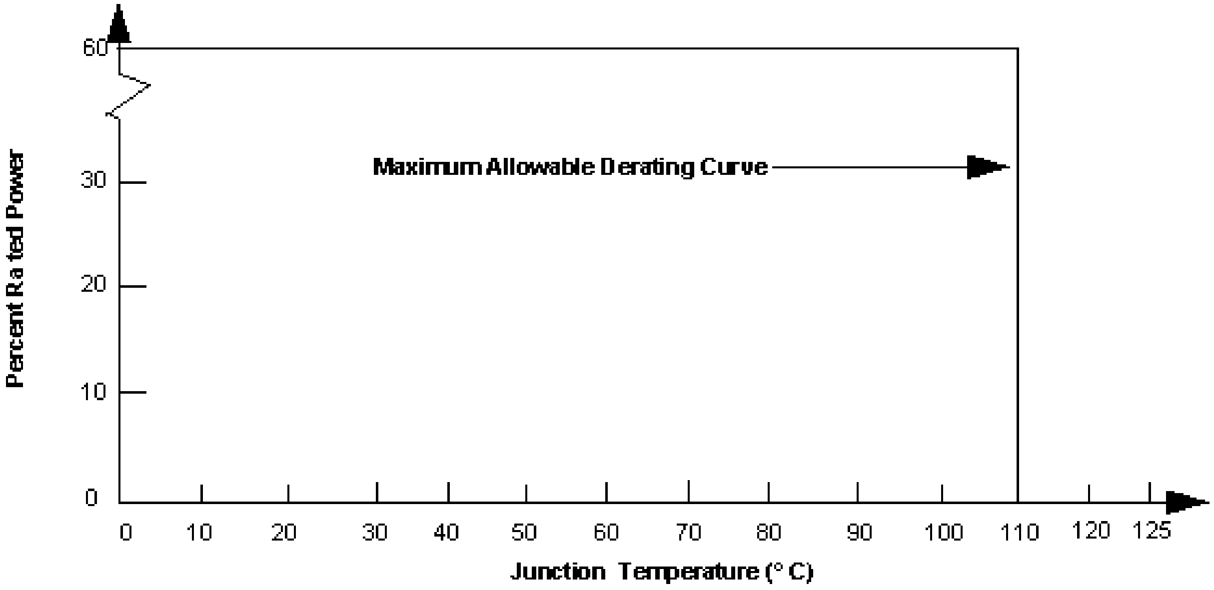

Figure 400.5 -- Derating Requirements for Hermetically Sealed Voltage Regulators With T_S = 110ºC

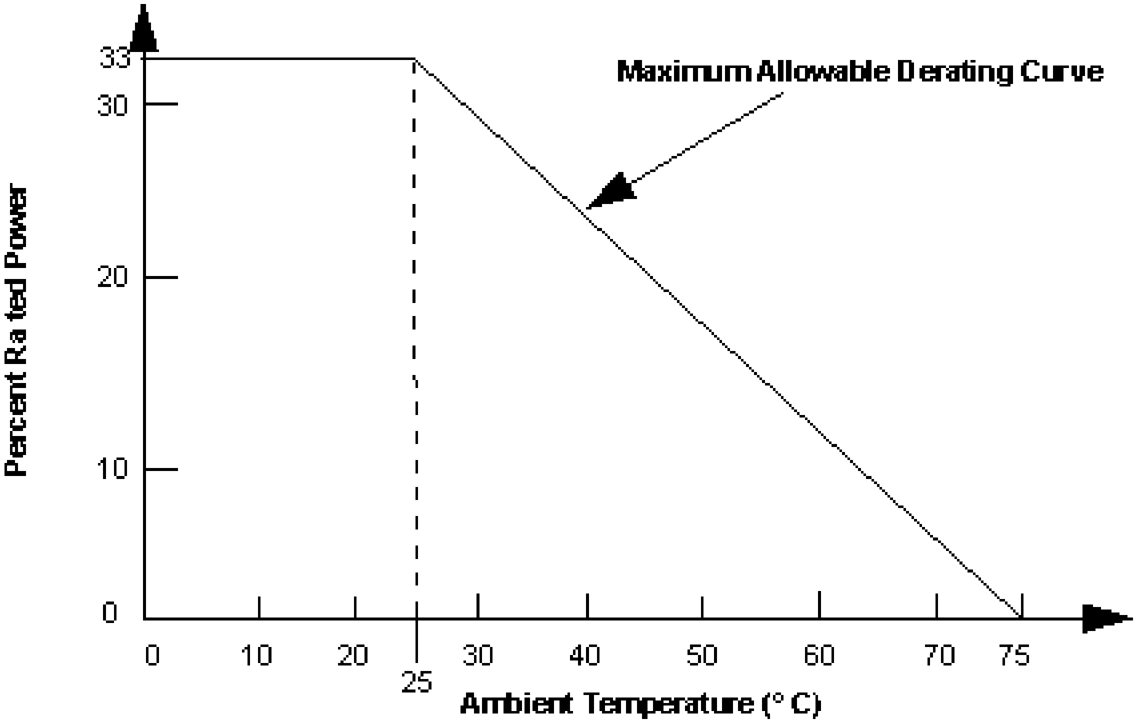

Figure 400.6 -- Derating Requirements for all Nonhermetically Sealed Microcircuits, Except Voltage Regulators, With T_S = 25ºC

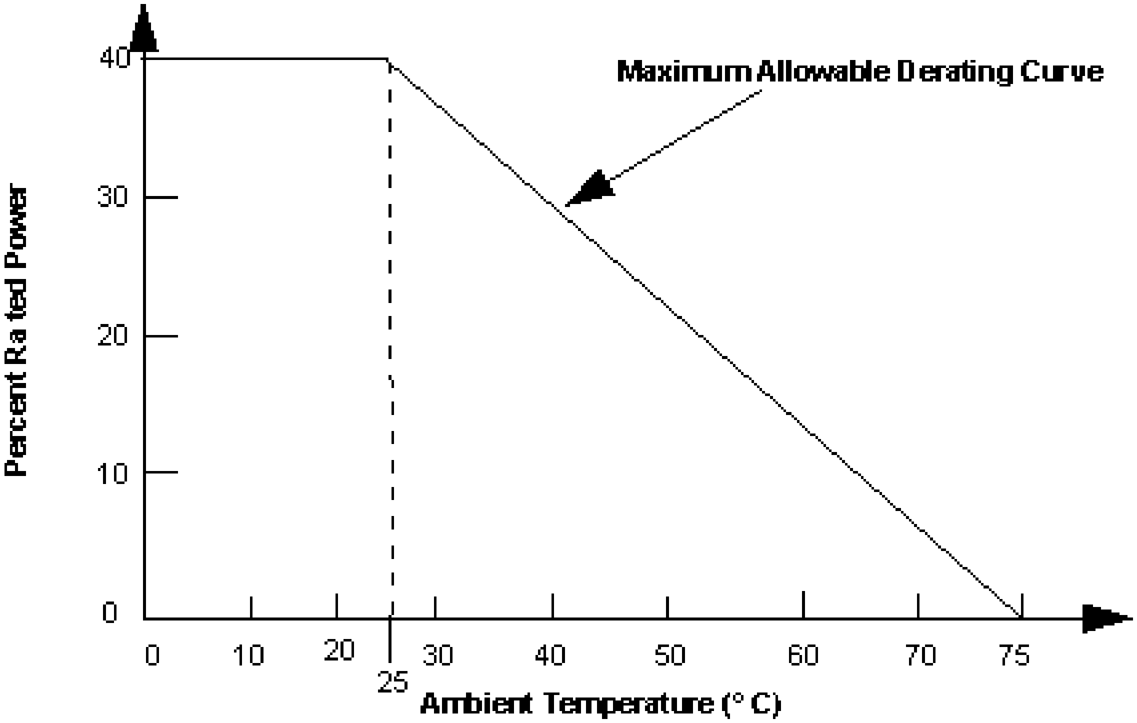

Figure 400.7 -- Derating Requirements for Nonhermetically Sealed Voltage Regulators With T_S = 25ºC

Note: Nonhermetically sealed microcircuits shall not be used without approval from the procuring activity.

In addition to limitations of the above derating curves, the following parameters shall be limited as follows:

Table 400-IIIA -- provides derating parameters for linear hermetically sealed microcircuits.

Table 400-IIIB -- provides derating parameters for linear nonhermetically sealed microcircuits.

Table 400-IV -- provides derating parameters for digital microcircuits.

Note: Maximum Junction Temperature 110ºC for Tables 400-III

<u>*Table 400-IIIA**</u>

Parameter	**% of Max. rated value**
Current (continuous)	70

Current (surge)	60
Voltage (signal)	75
Voltage (surge)	80
Supply voltage	**Do not exceed mfg. Nominal rating**

Derating Parameters for Linear Hermetically Sealed Microcircuits.

Table 400-IIIB

Parameter	**% of Max. rated value**
Current (continuous)	60
Current (surge)	60
Voltage (signal)	75
Voltage (surge)	80
Supply voltage	**Do not exceed mfg. nominal rating**

Derating Parameters for Linear Nonhermetically Sealed Microcircuits.

* Combination of AC and DC loads is not recommended for linear microcircuits.

Table 400-IV

Parameter	**% of Max. rated value**
Junction temps.	*100ºC max.
Supply voltage	**Do not exceed mfg. nominal rating**

Toggle frequency	**70**
Set up & hold time	200 min.
Fanout	80

Derating Parameters for Digital Microcircuits

* This value represents the actual temperature and not a percentage.

401.2 Quality Level

Microelectronic devices shall be selected in accordance with MIL-STD-454, Requirement 64.

401.1.1 Some special considerations:

a. There may occur, from time-to-time, instances in which nonstandard ICs are approved for uses which have maximum function temperatures which do not exceed 75ºC. In these instances, derate the 75ºC maximum rating to 60ºC.

b. Gallium Arsenide (GaAs) digital device (both discrete as well as integrated networks) maximum junction temperature should not exceed 160ºC. GaAs and Gallium Phosphide (GaP) power devices should not exceed 200ºC. These increases in maximum junction temperature is primarily due to the Ga metallic interface characteristics versus the oxide stresses prevalent in Si devices.

402 Micron/Submicron Digital Devices: Very High Speed Integrated Circuits (VHSIC) And VLSI ICs

402.1 General Information

The goal of the VHSIC program is to develop advanced semiconductor technology for military applications and to reduce the delay experienced by the Department of Defense in introducing such technology into military hardware. This section is intended to facilitate that goal while reducing the government’s exposure to undue risks.

The acronym VHSIC refers to the DoD technology development program (1980 -- 1989) for the design and manufacture of high speed digital circuits with 1.25 and 0.5 micrometer feature sizes for military use. Although the official DoD VHSIC program came to completion in FY 89, VHSIC manufacturing technology insertion, and submicron chip development continues. Device feature size is the minimum lateral dimension of the integrated circuit as defined by the lithographic process during fabrication. A prime example is the dimension of transistor gate length.

Information provided by this section is applicable to all digital micron and submicron ICs meeting the general requirements of VHSIC devices such as testability, speed, feature size and

VHSIC Hardware Description Language (VHDL) documentation. In this sense, VHSIC is used as a generic term to mean 2.0 micron technologies and smaller. VHSIC components are in essence high density Very Large Scale Integration (VLSI) ICs. The density increase is accomplished by scaling devices to very small geometries with a corresponding increase in the Functional Throughput Rate (FTR). FTR (Gate-Hz/sq. cm) is defined as the product of on-chip clock speed (Hz) and the gate density (logic gates per square centimeter).

Parallel to the design and manufacture of VHSIC chips, supporting technologies have evolved in design automation and lithography. VHDL has been incorporated in IEEE-1076, and all digital Application-Specific Integrated Circuits (ASICs) designed after 30 September 1988 are required to be documented by structural and behavioral VHDL syntax.

Electron beam lithography has been a key technology in the fabrication of submicron chips. E-beam lithographic equipment with high wafer throughput is necessary to enhance yield and reduce unit cost. This development will eventually permit circuit patterns with feature size as small as 0.25 micron. Since X-rays have extremely short wavelengths, X-ray lithography is critical for the fabrication of next generation chips. With advances in X-ray optics, the fabrication of pilot line 0.10 micron devices is feasible although not anticipated until the mid to late 1990s.

Single-chip VHSIC packages as well as multi-chip sets are available for technology insertion. The predominant technology in use is CMOS due to its low power requirements, noise immunity, and radiation hardness capability. In VHSIC-based systems, a trade-off study of the type of technology to be used should be performed and be submitted to the Government. VHSIC technology insertions have been successfully demonstrated by the Navy and other services in a number of critical programs. VHSIC technology has matured to a level where it can be deployed in new systems and retrofit existing systems. Advantages of VHSIC include an increase in reliability due to a reduction in the number of components and interconnects, reduction in size and weight of existing hardware, and a reduction in power consumption.

402.2 Package Types

VHSIC technology chips are typically produced in two basic types of single chip packages: perimeter chip carriers and grid array packages, shown in Figures 400.9A and 400.9B, respectively. For certain non-VHSIC micron chips, Dual-In-Line Packages (DIP) and flatpack packages are available. Most packages are hermetically sealed ceramic. The selection of package type depends on the application. Multi-chip Packages (MCPs) are also available for high speed requirements. An example of a MCP is illustrated in Figure 400.10.

402.2.1 Perimeter Type Packages

The perimeter type package can be Leaded Chip Carriers (LDCC) or Leadless Chip Carriers (LCC) with I/O counts in the hundreds. The primary advantage of the leadless chip carrier is its small footprint, which is important on densely populated boards. LCC provides for increased switching speeds due to shortened circuit paths. However, associated with LCC packages are mounting problems caused by possible mismatch in the Thermal Coefficients of Expansion (TCE) between the package and the board. Therefore, the leaded packages are more widely used. A primary problem associated with the use of the leaded package is the possibility of damage to leads during handling and testing.

VHSIC chips use two types of LDCC packages, J-Hook and Gull Wing lead packages. The Gull Wing package is more widely used. Gull Wing leads allow the dimensions of the package to change with respect to the Printed Wiring Board (PWB) during thermal cycling. This provides a strain-accommodating interface that serves to reduce stresses on solder joints. However, each configuration has its own advantages and disadvantages, summarized in Table 400-V. Advantages shared by both are: proven processes, easy auto-positioning, and resilient placement and replacement.

402.2.2 Grid Array Packages

The Grid Array package is available in two types of packages: Pin Grid Array and Pad Grid Array. The packages can contain up to 500 I/O connections. The Grid Array package should be used for high pin count applications since it has more I/O connections than the perimeter type. The Pin Grid Array is a square multi-layered ceramic body with rows of pins exiting the base of the package in a grid pattern. The Pad Grid Array package is the surface mount counterpart of the Pin Grid Array package. The Pad Grid Array has an area pad array of solderable bonding pads for electrical connection to the underlying substrate. The primary reason for the limited use of the Pin Grid Array is the difficulty of inspecting solder joints underneath the package due to minimal component standoff height. For this reason Pin Grid Arrays are not recommended for Navy programs.

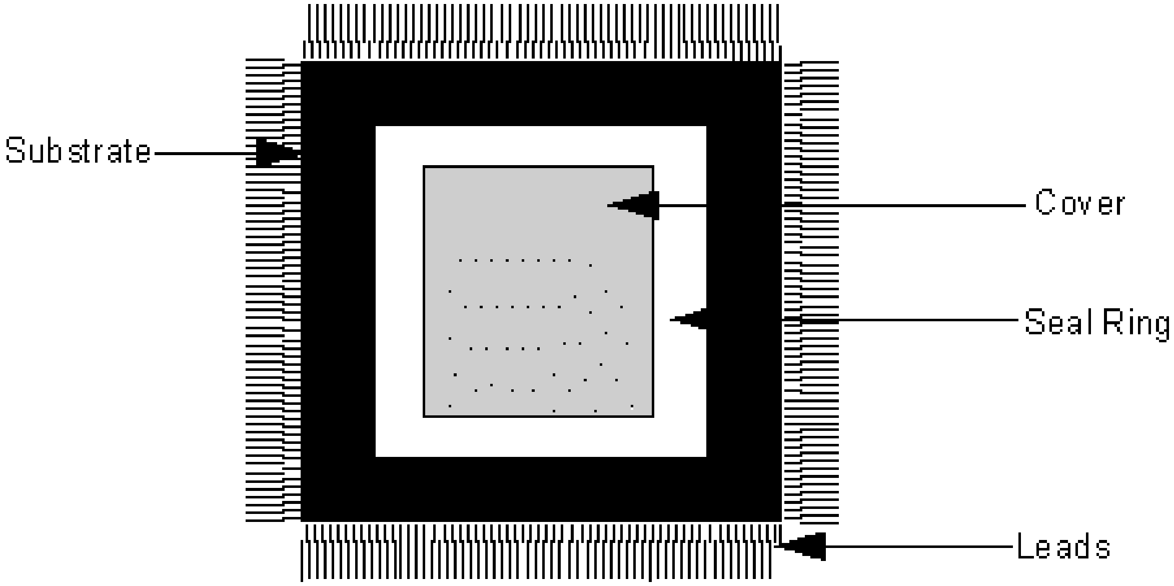

Figure 400.9A -- Perimeter Chip Carrier

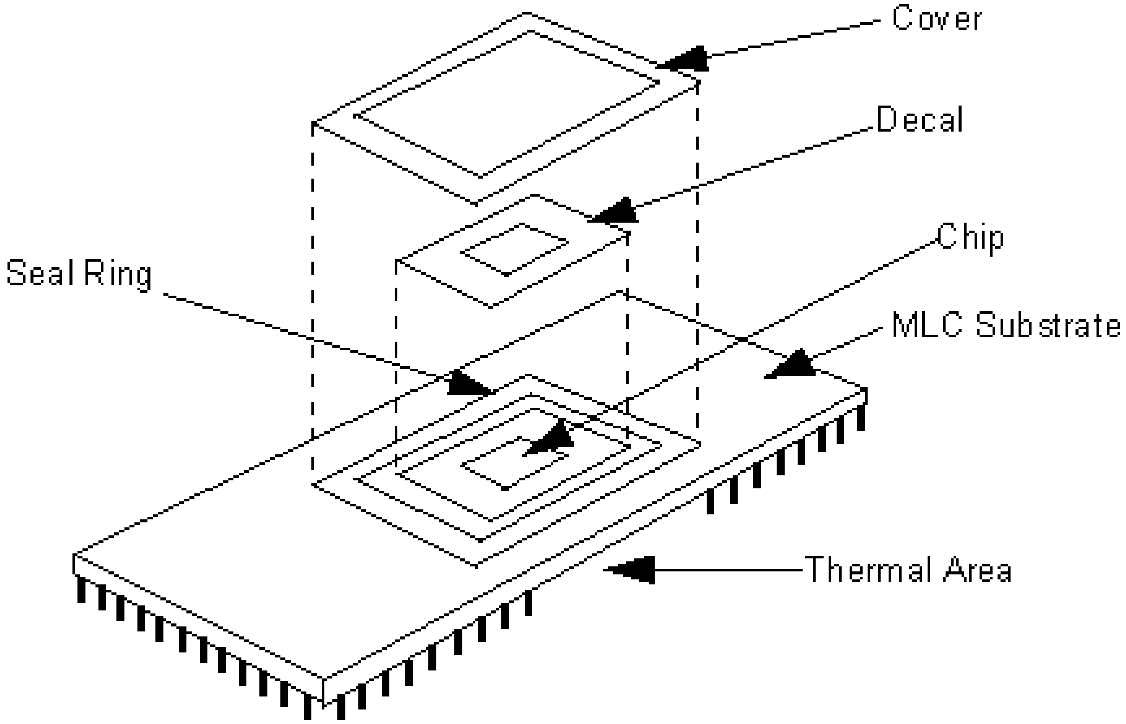

Figure 400.9B -- Pin Grid Array Package

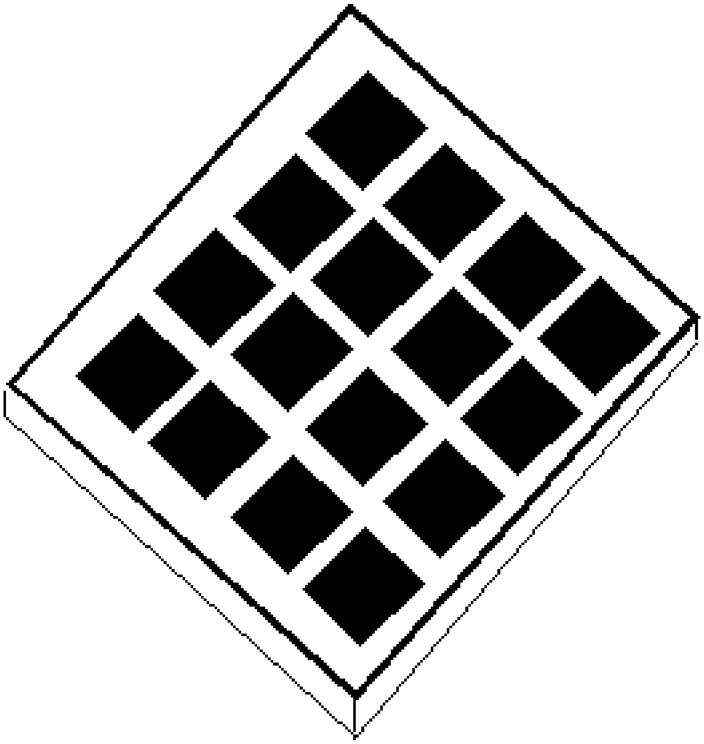

Figure 400.10 -- Multi-Chip Package

Grid Array packages are available in two cavity orientations, cavity-up and cavity-down. The cavity-up configuration mounts the chip upside down in the package with the leads facing up. The physical contact with the package substrate enables heat to dissipate from the ceramic chip through the package substrate to a heat sink on the bottom of the package. The cavity-up version is the most popular and accommodates a higher I/O count than the cavity-down. However, the thermal dissipation capability of the cavity-up is less than that of the cavity-down version.

402.2.3 Multi-Chip Packages

Multi-Chip Packages (MCPs) are available for VHSIC chips. The packages are Pin Grid Array packages which connect to the board with the possibility of over 600 I/O connections. The MCP should be used in high speed applications to take advantage of the increased speed capability of submicron chips. The speed performance is enhanced by shorter interconnections within the package as opposed to individual packages. MCPs are hermetically sealed ceramic modules which can house a number of chips, typically 5 to 16. The MCP uses thin film multi-layer copper conductors with polyimide dielectric for chip-to-chip interconnections. Chip-to-chip interconnection can be incorporated in a multi-layer Tape Automated Bonding (TAB) system customized for each chip combination. The package also has distributed power and ground planes and provisions for decoupling capacitors.

402.2.4 Chip-to-Package Electrical Interconnection

The three most common chip-to-package electrical interconnection schemes are wirebonding, tape bonding, (TAB) and flip-chip or solder bumping techniques. Table 400-VI compares these alternate interconnection methods to assist in the selection of the appropriate method.

Table 400-V. Trade-Off Comparison of Different Packages Lead Configuration

Package Lead Configuration	Advantages	Disadvantages
J-Hook	• Minimum Footprint, Maximum Board Density • Minimum Footprint, Inspection and Repair Problems • JEDEC Standards Exist • Leads Well-Protected • Leads are Compliant, Usable with PC Board and Ceramic Substrates	• Higher Profile • Invisible Leads Present Testing. • Possibility of the Hook Filling with Solder, Loss of Lead Compliance
Gull Wing	• Positive Solder Inspection • Allow for Easy Testing • Coplanarity Enhancement	• Lead Susceptibility to Damage • Footprint Size Larger Than LCC, Real Estate Penalty • Difficult to Socket.

ADVANTAGES		
Wire Bond	**Tab**	**Flip-Chip**
Layout Flexibility	Mass Bonding	Mass Bonding
Short Turnaround Time	Allosw Chip Testing	Repairable
Die Attach Options	Good Heat Dissipation	High I/O Density
DISADVANTAGES		
Testability	Polymer in Package (Possible Moisture Intrusion and Corrosion)	Heat Transfer
Limitations of I/O Counts	Die Alignment	Testability
Control of Wire Impedances		Hidden Connections

Table 400-VI. Trade-Off Comparison of Alternate Electrical Interconnection Methods

Wirebonding is performed on integrated circuits after a die has been separated from a wafer and attached to the package or substrate. Gold or aluminum wires are typically used. There are several problems associated with the use of wirebonded interconnections with high density I/O and high speed, integrated-circuit chips. The primary concern is the possibility of shorting between adjacent wires. A second concern is the inability to control the impedance of the wire leads.

TAB is an alternate interconnection method which achieves reliability, electrical performance. and density that are not possible with wirebonding techniques. It is difficult to produce reliable wirebond interconnections due to the fine lead pitch and high lead counts on VHSIC chips. To date, wirebonding machines have not advanced to the level required to perform chip-to-package interconnections without possible wire crossings. The TAB process is also considerably faster than automatic wirebonding. TAB involves the use of prefabricated metallic interconnection patterns on a carrier film, typically polyimide. Polyimide can bring moisture and other contaminants into the hermetically sealed package. However, as a result of improvements in TAB processes, moisture contamination is not as likely as was once believed.

A third method is solder bumping or flip-chip. In this attachment technique, solder nodules or bumps are attached to the chip bonding pads and the substrate lead pattern. The die is then inverted over the substrate and bonding is accomplished by a reflow method. Solder bumping provides very short, low-resistance leads, which minimizes lead inductance. This is particularly useful for the high-frequency operations encountered in VHSIC chips. The disadvantages in this process include solder joints under the chip that are not fully inspectable prior to packaging and poor heat transfer since the only path is through the solder bumps.

402.3 Mounting

The mounting method is dependent upon the type of package selected. There are two basic techniques for attaching packaged chips to circuit boards. Through-hole mounting and surface mounting. Since there may be a large TCE mismatch between the PWB and the device, solder joint problems may result when using LCC packages. This is especially the case for large ICs such as VHSIC-type devices. Surface mounted leadless chip carriers with pin counts greater than 24 should not be used unless the contractor can verify that reliability requirements will not be adversely affected. The following sections describe the different methods of mounting as well as various reliability considerations. The most reliable and recommended configuration of the discussed package and mounting techniques is the Gull Wing leaded package surface mounted to a ceramic board.

402.3.1 Grid Array Package Mounting and Connection

The Pin Grid Array package requires the use of plated-through hole mounting techniques for connection to the circuit board. These holes hold component leads and serve as conduits, or vias for interconnections between the circuit board layers. This type of mounting has several disadvantages for VHSIC applications, which include reduced circuit board density (due to the through-hole via structure), difficulty of repair (removing package leads can damage through-hole structures, especially as I/O numbers increase), and increased inductance due to long round wire leads. To avoid hole mounting by use of surface mounting, the pins may be modified or a Pad Grid Array may be used. However, surface mounting has a number of associated problems which have not been resolved, as discussed in Section 402.3.2. Therefore, for high I/O count applications, the hole mounted Pin Grid Array package is recommended and is currently the most commonly used Grid Array package.

402.3.2 Perimeter Package Mounting and Connection

Perimeter type packages, both leadless and leaded, are connected to the board using Surface Mount Technology. Surface mounting of leadless, Gull Wing, or J-Hook leaded components to various circuit board materials is the dominant thrust in modern device packaging. In this technique, leaded or leadless packages are soldered to the surface of the circuit board. No through-hole mounting is required. Vias are made without through-hole drilling and plating, allowing an increase in circuit board density. Repair is also easier since most joints are accessible and not locked into holes.

One of the main reliability concerns of Surface Mount Technology is solder joint integrity. This is because the solder joint acts as both electrical and mechanical connection between the component and the board. One factor which affects the solder joint is the difference in the TCE between the printed wiring board and the chip carrier. When materials with different TCEs are joined and exposed to temperature variations, mechanical stresses due to TCE result. Such stress is applied directly to the solder joint. To minimize this mechanical stress, the following guidelines should be followed:

a. Match the PC board material and interconnection material TCEs with that of the chip carrier. Inner core materials which should be considered are copper-invar-copper, copper-molybdenum-copper, and epoxy graphite.

b. Increase solder thickness fillet size.

c. Develop a substrate with compliant top layers that can absorb the stress.

d. Affix or manufacture ceramic chip carriers with leads, since the leads act as compliant members between the package and the board.

Table 400-VII lists TCEs of various materials used in packages and substrates. TCE mismatch between the package and substrate should not exceed 2 PPM/ºC for LCC. In the event that TCE mismatch is large, the contractor should verify that system reliability has not been adversely affected.

402.3.3 Board Layout of VHSIC Chips

Refer to MIL-STD-2000 for component mounting guidelines and acceptance criteria. When analog and digital ICs are mounted on the same board, separate analog and digital ground planes must be used to protect the analog circuits from digital noise corruption.

Table 400-VII. Thermal Coefficients of Expansion of Various Materials

Material	**TCE (XY) PPM/ºC**
Plastic Composition Chip Carriers	6 to 7
$AL_2 O_3$ Ceramic Chip Carriers	5 to 7
Alloy 42	5
Copper-Clad Invar	5 to 6
Copper-Clad Molybdenum	5 to 6
Carbon-Fiber/Epoxy Composite	-5.5 to +2
Kevlar Fiber	-2 to-4
Quartz Fiber	0.54
Glass Fiber	4 to 5
Epoxy/Glass Laminate	12 to 16
Polyimide/Glass Laminate	11 to 14

Polyimide/Kevlar Laminate	3 to 8
Polyimide/Quartz Laminate	6 to 9
Epoxy/Kevlar Laminate	6 to 8
Aluminum	18 to 24
Copper	17

402.4 Heat Dissipation

Since operating temperature is one of the critical attributes affecting reliability, it is essential that sufficient cooling precautions be taken to assure adequate heat dissipation. The amount of heat produced is proportional to the power. Power dissipation of VHSIC chips varies from .5 Watt to 5 Watts per chip, and up to 30 Watts for the multi-chip package. Typically, single-chip packages range in size from one square inch to four square inches. Multi-chip packages can be up to 9 square inches in size.

The primary means of dissipating generated heat is through the package base and mounting to the printed circuit board or ceramic substrate. Ceramic packages, either alumina or beryllium oxide, offer better thermal conductivity than other packages. Thermal pads, placed directly under the die, can be bonded to the substrate to enhance thermal conductivity. Heat sinks may also be used to enhance heat transfer. The ideal placement of the heat sink would be in direct contact with the bottom of the chip or package.

402.5 Reliability Prediction

Unless otherwise specified by contract, a reliability prediction should be performed; such requirements should also address use of one of two models developed by the Rome Air Development Center (RADC) to determine failure rates of VHSIC devices. The short form Model is based on the format established in MIL-HDBK-217 for use by reliability and system engineers and is satisfactory for purposes of the prediction. The detailed form is intended as a scientific model to be utilized as an in-depth analytical tool.

Both short and detailed models were developed for CMOS VHSIC devices but may be applied to other MOS integrated circuits. However, the models should not be extrapolated to determine failure rates of Bipolar components. Failure rates obtained from other sources require the approval of the procuring activity. A brief discussion of the models is presented in 402.5.1 and 402.5.2 to provide some familiarization.

402.5.1 Short Form Model

This model is derived from the detailed model and includes only those parameters that can readily be obtained. The failure rate factors are listed in Table 400-VIIIA through Table 400-VIIIF.

$\lambda p = \mathbf{[}\lambda BD\ \ \pi MFG\ \ \pi T\ \ \pi SD\ \ \pi CD\mathbf{]} + \mathbf{[}\lambda BP\ \ \pi E\ \ \pi SP\ \ \pi PT + \lambda EOS\mathbf{]}$

λp = Part Failure Rate/10^6 hours

λBD = Die Base Failure Rate
= .020 for Custom and Logic Devices
= .030 for Memories and Gate Arrays

πMFG = Manufacturing Process Correction Factor (Table 400-VIIIA)

Table 400-VIIIA. Manufacturing Process Correction Factor (π_{MFG})*

Manufacturing Process	πMfg
QML or QPL	.55
Non QML or Non QPL	2.0

*	Refer to Section 402.11 for descriptions of QML and QPL.

Table 400-VIIIB. Die Screening Correction Factor (π_{SD})*

Quality Level	πSD
D	1.0
B	.94
S	.85

*	Refer to MIL-HDBK-217 for Definitions of Quality Levels.

Table 400-VIIIC. Die Complexity Screening Factor (π_{CD})

	Die Area (CM^2)				
Feature Size (Micron)	**.1-.2**	**.2-.4**	**.4-1.0**	**1.0-2.0**	**2.0-3.0**
1.0	2.1	4.0	8.7	18	30
1.2	1.6	2.8	6.1	12	21

1.5	1.2	2.0	4.1	8.7	14
2.0	.81	1.3	2.5	4.9	8.0
2.5	.65	.95	1.7	3.3	5.2
3.0	.56	.76	1.3	2.3	3.7

Table 400-VIIID. Application Environment Factors (π_E)*

Environment	E	Environment	E
G_B	.52	A_{IB}	6.8
G_{MS}	.88	A_{IA}	5.4
G_F	3.4	A_{IF}	8.1
G_M	5.7	A_{UC}	4.0
M_P	5.2	A_{UT}	5.4
N_{SB}	5.4	A_{UB}	10
N_S	5.4	A_{UA}	8.1
N_U	7.7	A_{UF}	12
N_H	8.0	S_F	1.2
N_{UU}	8.6	M_{FF}	5.3
A_{RW}	12	M_{FA}	15
A_{IC}	3.4	M_L	17
A_{IT}	4.0	C_L	300

* Refer to MIL-HDBK-217 for Definitions of Application Environments.

Table 400-VIIIE. Package Screening Factor (π_{SP})*

Screen Level	Quality Level	πSP

None	D	10
Burn-In	-	8.0
Environmental	-	2.8
Burn-In/Environmental	B	1.0

* Refer to MIL-HDBK-217 for Definitions of Quality Levels

Table 400-VIIIF. Package Type Correction Factor (π_{PT})

Package Type	**πPT**	
	Hermetic	**Nonhermetic**
Dip	1.0	2.8
Pin Grid Array	2.2	4.0
Chip Carrier	4.7	6.5

T = Temperature Factor

= e^{-3824} (1/T_J -- 1/298)

e = Natural Logarithm Base, 2.718 …..

T_J = Junction Temperature (°C)

π_{SD} = Die Screening Correction Factor (Table 400-IXB)

πCD = Die Complexity Screening Factor (Table 400-IXC)

λBP = Package Base Failure Rate

= .0024 + (1.85 x 10-5)(# pins)

πE = Application Environment Factor (Table 400-IXD)

πSP = Package Screening Factor (Table 400-IXE)

πPT = Package Type correction Factor (Table 400-IXF)

λEOS = Electrical Overstress/Electrostatic Discharge Failure Rate

$$= \frac{-1n\left[1-.00057\ e^{\left[-\ .0002\ V_{TH}\right]}\right]}{.00876}$$

Where V_{TH} is the ESD Threshold level of the device using a 100 pF, 1500 ohm discharge model. Typically, integrated circuits are found to be susceptible to damage by electrostatic discharge. ESD handling precautions in compliance with or compatible with DOD-STD-1686 and DOD-HDBK-263 should be observed.

402.5.2 Detailed Model

This model calculates the part failure rate based on the aggregate failure rates of various failure mechanisms. These mechanisms include hot charge carrier effect and metallization. It also provides the input parameters necessary to apply the model and their default values.

$\lambda p^{(t)}$ = $\left[\lambda OX^{(t)} + \lambda MET^{(t)} + \lambda HC^{(t)} + \lambda CON^{(t)} + \lambda PAC + \lambda ESD + \lambda MIS^{(t)}\right] \pi C$

$\lambda p^{(t)}$ = Predicted Failure Rate as a Function of Time

$\lambda OX^{(t)}$ = Oxide Failure Rate

$\lambda MET^{(t)}$ = Metallization Failure Rate

$\lambda HC^{(t)}$ = Hot Carrier Failure Rate

$\lambda CON^{(t)}$ = Contamination Failure Rate

λPAC = Package Failure Rate

λESD = EOS/ESD Failure Rate

$\lambda MIS^{(t)}$ = Miscellaneous Failure Rate

πC = Field Correction Factor

The equations for each of the above failure rates are provided in the model and can be obtained from RADC.

402.5.3 Failure Mechanisms

The detailed model incorporates failure mechanisms which contribute to the failure of these semiconductor devices. Both time-dependent and time-independent failures were considered in the development of the model. Among these mechanisms are metallization electromigration, hot charge carriers, and oxide failures.

Electromigration is caused by the transfer of momentum at elevated temperatures to metallic ions from current carrying electrons. If the current density increases sufficiently, the material of the conductor and interconnects may be pulled along to the positive end of the conductor, resulting in either voids or hillocks along conductor paths. A contributing factor to electromigration is formation of thermal gradients in the material causing variation in the diffusion properties of the conductor.

Hot charge carriers are either electrons or holes that have gained sufficient energy from the electric field to penetrate and then become trapped in the gate oxide resulting in transistor parameter shifts. Hot charge carrier degradation is a function of transistor geometry, applied bias voltages, relatively cold temperature, and oxide quality.

Oxide failures include defect-related and wearout-type oxide breakdowns. The model takes into consideration the thickness of the gate oxide and the maximum power supply voltage (V_{DD}).

Electromigration, hot charge carrier effects, and oxide defects or wearout all increase the probability of field failures. Appropriate design rules and process controls enhance device reliability and reduce failure rate. Oxide defect-related failures typically occur early in product life and devices with such defects are screenable by high-voltage stress or burn-in.

All VHSIC failures should be analyzed in-depth, failure modes identified, and corrective actions implemented.

402.6 Interoperability

VHSIC submicron chips incorporate electrical and physical interoperability features. Four specifications (electrical interface, ETM-Bus, TM-Bus, and PI-Bus) have been established (To date are in the process of being formally issued) defining standards for bus interfaces, clocks, and voltage levels for single and multi-chip packages. They facilitate the interface between the chips and provide a digital medium for data communication including the transfer of control and status bits to test individual devices. These specifications are intended for implementation in any VHSIC-based system or subsystem employing VHSIC submicron chips and chip sets. These systems or subsystems should exploit the interoperability standards. The use of other schemes will require prior approval of the procuring activity.

The four standards include three bus specifications and an electrical specification. The Parallel Interface (PI) bus is configurable either as a 16-bit (single word) or 32-bit (double word) parallel bus with either simple parity or single-error correction double-error detection (SECDED) encoding. The bus can support up to 32 modules residing on a single backplane with extensive control and data lines. These standards assure that all VHSIC submicron chips can function together regardless of the supplier. Figure 400.11 illustrates a typical implementation of these standards.

The purpose and a general overview of each standard are given in Table 400.IX. For a full description and complete details, refer to the Interoperability Standards. The contractor should identify any exceptions that may exist in the implementation of the specifications invoked above.

402.7 Testability

As chips, boards, and systems become more complex, engineers should adopt a Design-For-Test (DFT) philosophy to develop easily testable and maintainable products. This approach reduces, maintenance costs, increases overall availability, and underlies the Navy's at-sea maintainability policy and requirements. Current VHSIC chip methodology employs Built-In Test/Built-In Self Test (BIT/BIST) features which should be exploited to enhance system testability and maintainability.

In VHSIC-based systems, control of the on-chip BIT/BIST is achieved via the interoperability bus schemes. The ETM-Bus provides a serial path for direct communication between the elements (devices), while the TM-Bus provides the interface at the board or module level. To initiate BIT routines, a maintenance controller would transmit control signals to various elements and in turn receive element status signals. Actual instructions issued to elements are provided by the device manufacturer and not by the Interoperability Standards.

402.8 VHSIC Hardware Description Language (VHDL)

All digital Application Specific Integrated Circuits (ASICs) designed after 30 September 1988 are to be documented by means of structural and behavioral VHDL descriptions in conformance with IEEE-1076 and as specified by MIL-STD-454, Requirement 64. It is anticipated that VHDL will become a mandated standard for more categories of electronic systems at various levels of hardware development and design abstractions, consequently, it should be used wherever applicable. VHDL documentation shall be in accordance with DI-EGDS-80811, VHSIC Hardware Description Language (VHDL) Documentation.

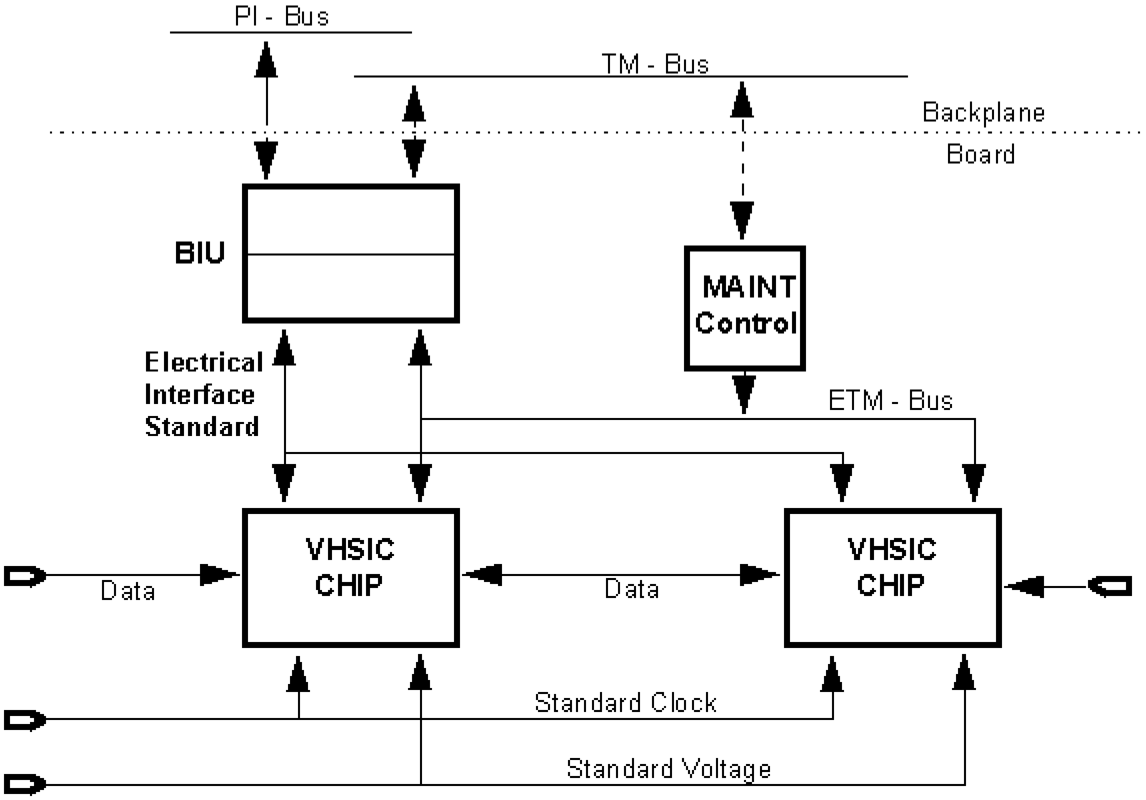

Figure 400.11 -- Typical Use of Interoperability Standards

Table 400.IX. -- Interoperability Standards

Specification	**Purpose**	**General Overview**
Electrical interface	• Establish electrical interface and clock standards for VHSIC submicron Ics.	• Two synchronous clock signals distributed to subsustems, Sysclk (System Clock) and Dfnclk (Definition Clock). The Dfnclk is intended as a synchronization signal to keep the various chips and applications in step with one another. • Chip power supplies, + 3.3V ± 5% and + 5.pV ± 10 %. • Logic levels for PT-to-PT Binary Data Interchange.
ETM-Bus (Element Test and Maintenance Bus	• Establish Requirements For the ETM-Bus and Facilitate interoperability of VLSI chips using	• Element refers to a single VLSI IC interfacing the ETM-Bus • Sychronous serial path for test and maintenance control and data information at the

	ETM-Bus	chip level • Data transfer synchronous with Refclk (Reference Clock) signam • Allows the monitoring of up to 32 individual devices within a module. • It is capable of supporting ring, star, multidrop and tree configurations.
TM-Bus (Test and Maintenance Bus)	• Establish Requirements for the TM-Bus and Facilitate interoperability of modules using TM-Bus	• Serial, Synchronous, multidrop communication path for serial data transfer between a controller module and up to 32 modules residing on a single backplane. • Four undirectional lines are defined; clock, control and two data lines. • Defines message protocols, broadcast capability, multicast capability, and TM-Bus interupts • Clock Frequencies 0 Hz to 6.25 Mhz.
PI-Bus (Parallel Interface Bus)	• Establish Requirement for the PI-Bus and Facilitate interoperability of modules using PI-Bus	• Synchronous, multidrop bus that supports digital message communications between up to 32 modules residing on a single backplane. • Datum size of 16 bits (single word) or 32 bits (double word) • Messages can be routed to particular modules using either logical or physical addressing. • The protocol specifies a set of bus state transitions to control the communications sequence and allow operation at maximum clock rate. • Signal line and sequence error detection capability is incorporated into the bus definition with an optional single line error correction.

* These standards are copyrighted documents and may be copied only in their entirety.

VHDL is a Hardware Description Language (HDL) which was initiated by the Department of Defense to provide standard documentation for the design, procurement, and logistics of very complex components and systems. The development of VHDL began under the auspices of the VHSIC Program Office. The high level software support environment funded by DoD is illustrated in Figure 400.12

The analyzer checks the source document, verifies the syntax, and converts it to an intermediate format which is then used by the simulator to dynamically verify the design. Digital circuits can be exercised and validated without the intermediate step of prototyping. A Design Library Manager organizes and accesses the intermediate form data stored and maintained in a Design Library database. Various tool sets have been marketed by vendors to support VHDL and its implementation, including analyzers, simulators, and translators. The tool sets either accept VHDL inputs or generate VHDL output descriptions. Although VHDL describes digital circuitry, it has some capabilities relating to analog networks. Analog portions of circuits are expected to be described and documented by an analog HDL at some future date.

A system can be documented by a hierarchy of VHDL modules similar to its physical hierarchy. VHDL constructs can express structural and behavioral aspects at a wide range of design abstractions from the system to the gate level and is being extended into switch levels as illustrated in Figure 400.13. Currently, VHDL does not describe circuits at the level of the transistor. The focus of VHDL is to aid in reprocurement, maintenance, and support of digital systems acquired by the Department of Defense.

402.8.1 Tester Independent Support Software System (TISSS)

The purpose of T1SSS is to automate the generation and maintenance of electrical test specifications and test programs for VHSIC and VLSI devices. It is a database-centered software support system that is independent of both Computer Aided Design (CAD) and tester environments. This allows the maintenance of electrical specifications in a standardized, transportable, computerized format that can automatically generate test programs. The input to the TISSS system is the appropriate VHDL description of the device. Such data permits the reprocurement of devices that have been discontinued by the original manufacturer. TISSS should be used for electrical test specifications and test program generation unless otherwise specified.

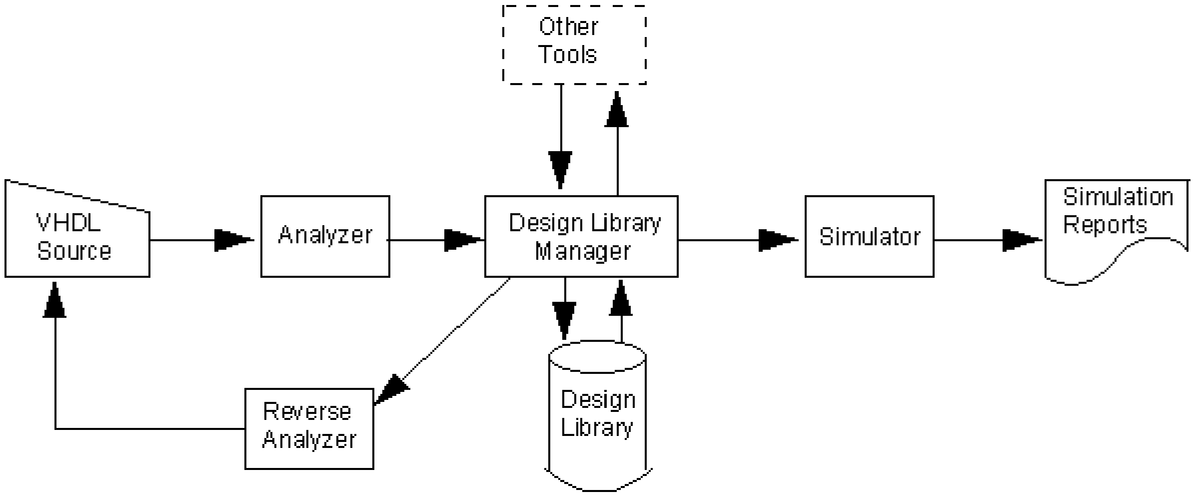

Figure 400.12 -- DoD Funded VHDL Software Support Environment

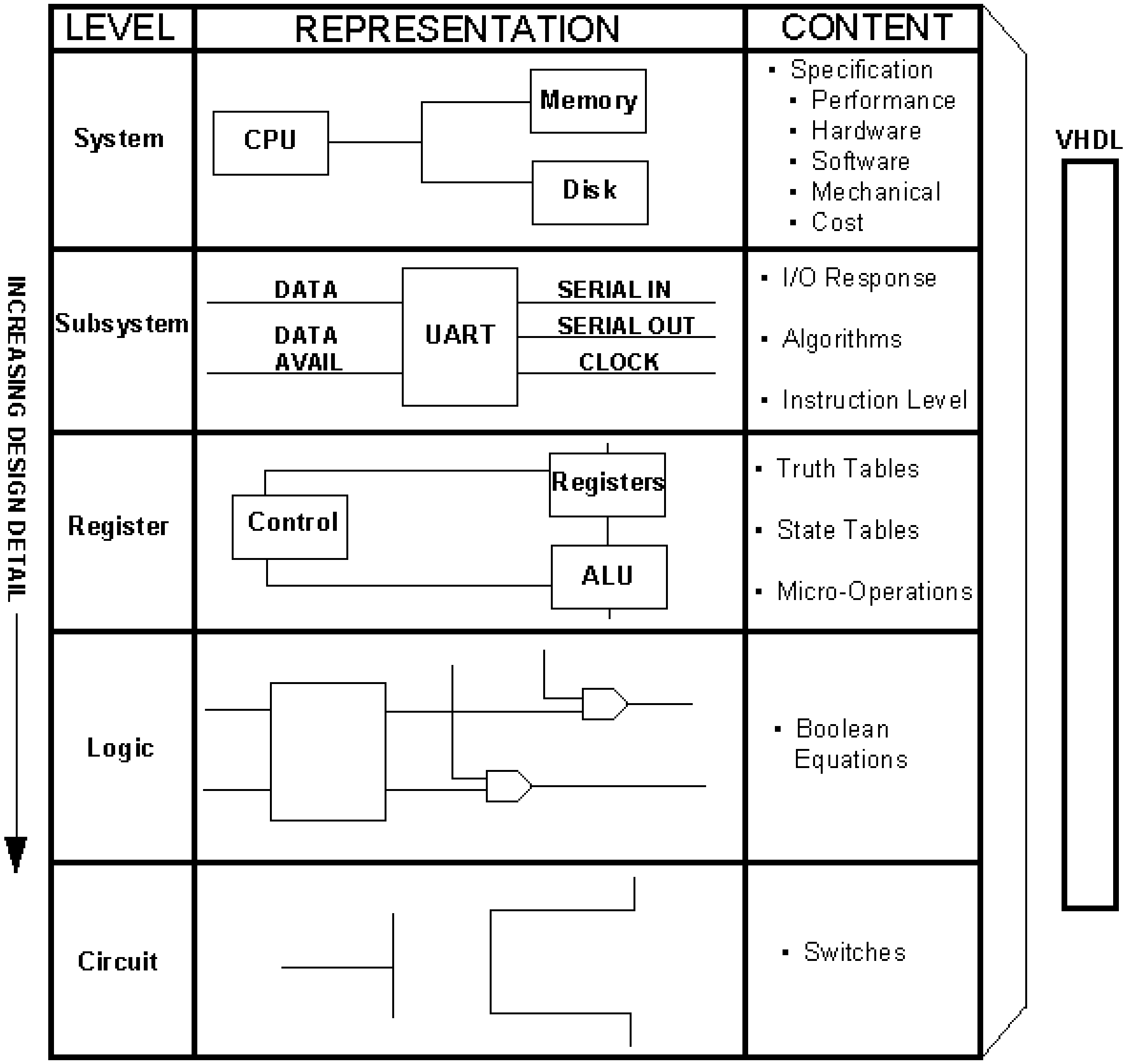

Figure 400.13 -- Range of Design Abstractions That can be Expressed by VHDL

402.9 Radiation Hardening

VHSIC devices have been hardened to withstand the damaging effects of radiation. Radiation by high energy particles introduces defects into semiconductor lattice structures. The particles of concern are electrons, protons, photons, alpha particles, neutrons and heavy ions. Two basic mechanisms dominate the effect of radiation on electronics. Displacement of atoms from their lattice sites (displacement damage), and generation of electron hole pairs (ionization). Radiation can cause permanent failures or performance degradation. VHSIC devices used in military applications should be hardened, as a minimum, to the requirements in Table 400-X. However, each application dictates its own radiation hardness requirements. Certain applications require VHSIC technologies which have been radiation hardened to space levels. Two military standards exist which deal with radiation hardening, MIL-M-38510 and MIL-STD-883.

MIL-STD-883 includes test procedures which define the requirements for testing sealed semiconductor devices for radiation effects.

Table 400-X lists the radiation threats and threshold requirements. These include: total dose, ionizing dose rate, single event, and neutron. Total dose is the total radiation energy received by a device from various radiation environments. This exposure causes a slow degradation of IC performance until a total permissible amount is reached, when permanent damage is caused. The permanent effects of ionizing total dose radiation on MDS device characteristics include threshold shifts, reduced device transconductance, and increased junction and surface leakage currents.

One of the effects of ionizing dose radiation is transient upset, which is a temporary electrical disturbance disrupting logic states. Another effect of ionizing dose radiation is circuit latch-up. Latch-up is a potentially disabling, high current condition caused by high energy, heavy ion strikes. A device is considered to be latched if a distinguishable change in power supply current persists 100 seconds after radiation exposure. A limit exists on the maximum ionizing dose radiation a device can receive without experiencing permanent damage. A device becomes permanently damaged if it ceases to be functional after irradiation or if it experiences burnout. Burnout is a catastrophic failure of a device resulting from radiation induced currents.

Single event upset (SEU) is a reversible change in a digital logic state caused by single ionizing particles. A high energy particle striking an integrated circuit element causes the production of electron hole pairs. The results include memory bit upset, microprocessor errors, CMOS latch-up, and burnout in electrically erasable PROMS. Single particles also produce effects that can cause permanent failures in circuit elements. Single heavy ions can produce a latch-up in CMOS circuits which can lead to burnout unless the power is removed. The particles of interest in terms of SEU are high energy protons, alpha particles, and heavy ions.

Table 400.X. -- Radiation Hardness Minimum Requirements

Radiation Type	**Effect**	**Micron Level**	**Submicron Level**	**Units**
Total Dose	Permanent Damage	10^4	5×10^4	RAD (Si)
Ionizing Dose Rate	Transient Upset	10^7	10^8	RAD (Si)/SEC
	Latchup	10^7	10^7	RAD (Si)/SEC
	Permanent Damage	10^8	10^{10}	RAD (Si)/SEC
Single Event	Upset	—	10^{-10}	Upsets/Bit-Day
Neutron	Permanent Damage	10^{11}	5×10^{12}	N/CM^2

VHSIC devices are also susceptible to a neutron environment. Neutrons cause both ionization and atomic displacement damage in semiconductor devices. Neutron irradiation tests are performed on devices to determine susceptibility to degradation in a neutron environment.

Device parameters must remain within specified limits after exposure to the required level of neutron fluence.

Another factor which can cause degradation of semiconductor devices is Electromagnetic Pulse (EMP). EMP creates currents which flow on a system's external surface and cables. These currents couple energy into the circuits and cause transient and/or permanent failures. Refer to Appendix F, Section F.2.2.4, for an EMP description.

Circuits vulnerable to EMP require design techniques which harden the system against EMP damage, including: shielding, filtering, component selection, and circuit layout. High clock speed circuitry is less susceptible to EMP. For further information regarding the speed threshold that impacts EMP susceptibility contact the Defense Nuclear Agency (DNA). The agency can also provide the minimum radiation hardness levels required for space applications.

402.10 Derating Requirements

When using VHSIC devices, power and other parameters should be derated according to the guidelines established in Section 401 of this manual. However, due to the nature of VHSIC architecture, the following maximum operating function temperature (T_j) should be observed, dependent on the line widths used in microcircuit fabrication:

Table 400.XI. -- T_j Versus Line Width

T_j	Line Width
$\leq$ 110ºC	2 microns
$\leq$ 100ºC	1.5 to 2 microns
$\leq$ 95ºC	1.0 to 1.5 microns
$\leq$ 85ºC	submicron

402.11 Quality Level

A generic qualification concept, Qualified Manufacturers List (QML), has been developed. This concept is based on Statistical Quality Control and Statistical Process Control (SQC/SPC) procedures whereby a microcircuit design and manufacturing process is characterized and continually monitored to assess its quality. QML is a new system which will run parallel to the Qualified Parts List (QPL). The quality of QML products will be equivalent to QPL-38510 Class B or higher. Only QML products or MIL-M-38510 Class B or higher quality levels should be used in systems incorporating VHSIC devices. Current Navy policy is directed toward QML as a preferred qualification methodology. Procedures for microcircuit QML will be in MIL-1-38535 "General Specification for Integrated Circuit Manufacturing."

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Section 500 -- Electrical Connectors

500 Electrical Connectors

500.1 General Information

Standard connectors are specified in MIL-STD-1353.

500.2 Application Considerations

500.2.1 Typical Electrical Characteristics to be Considered in the Selection of Connectors

a. Voltage and current requirements -- low current and low voltage situations, for example, require a plating that will not oxidize because the current may not be able to penetrate an oxide coating.

b. Resistance -- becomes a critical factor if connectors are in series and the impedances involved are low.

c. Maximum current -- determined by the connector and the size of wires attached to it, as well as contact size.

d. Maximum voltage -- depends on the spacing between contacts and insulating material used.

e. Intercontact capacitance -- becomes very important at high frequencies.

Other key electrical parameters include surge current, characteristic impedance, insertion loss, and EMI leakage attenuation.

500.2.2 Typical Mechanical Characteristics to be Considered in the Selection of Connectors

a. The space available for the connectors.

b. The number of necessary spare contacts.

c. The type of termination required (i.e., crimp or solder).

d. The type of connector required: environmental, nonenvironmental, threaded, bayonet or push-pull.

e. Size of contacts (determined by the operating voltages and currents).

f. The type of wire characteristics required: that is, whether contacts for shielded wire are required; whether RFI protection is required; and also the wire materials construction and diameter.

g. If crimped removable contacts are used, the direction of removal (i.e., front release-rear removable or rear release-rear removable).

h. The type of receptacle to be employed (i.e., square flange mount or single hole mount).

I. The type of support hardware (clamps, caps, etc.) required and mounting provisions to be made.

500.2.3 Environmental Conditions

500.2.3.1 Mechanical Effects

Achieving good electrical contact in a connector is a function of contact surface films, surface roughness, contact area, plastic deformation of the contacting materials, and load applied. Since 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 on chemical, thermal and mechanical behavior at these contact points.

500.2.3.2 Electrical Effects

Current flow between mating materials is constricted at the interface to those small points on the contact surfaces which are in electrical contact. This flow pattern causes differences of potential to exist along the contact interface, and causes current bunching at points of lower resistance. As a result, contact resistance and capacitance are introduced into the circuit, and certain chemical effects evolve (see 500.2.3.4 on chemical effects).

500.2.3.3 Thermal Effects

Since the total contact resistance in a good connector may be small (micro-ohms) and is achieved by the paralleling along the interface of many higher resistance point conducting paths, a series of localized hot spots can develop. When high currents are conducted through multiple pins. the cumulative heat rise in the connector can be appreciable.

a. ***High Temperature Effects*** -- 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 operating temperature increases, insulation tends to become more conductive, and simultaneously, the resistance of conductors increases. Higher resistance causes the temperature of the conductor and of its insulation to rise further. This pyramiding effect can raise conductors and connector contacts beyond maximum conductor operating temperatures, with resultant damage to contacts and conductive platings. Complete failure 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 ambient temperature and conductor temperature rise caused by the passage of current. For example, maximum conductor operating temperature of 125ºC is based on an ambient temperature of 100ºC, plus a rise of 25ºC, due to the conductor carrying current. A graph of service life versus hot spot temperature is provided in Figure 500-1.

b. ***Low Temperature Effects*** -- Metals and nonmetals tend to become brittle and contract in response to low temperature at different rates because of differing coefficients of expansion. How important each characteristic is depends on the application. Most high performance connectors will operate down to -55ºC. Operation at lower temperature may require special materials.

Ambient temperatures below "normal" are not usually the cause of trouble in interconnection systems, so far as conductivity is concerned. The lower the temperature, the more current can be carried by a given conductor. However, extremely low ambient temperatures do produce mechanical failures, mostly occurring in the nonmetallic portions of connectors, wires and cables. The coefficient of expansion of most plastics 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 may not cause a malfunction unless moisture and contaminants enter through the opening. If a seal opens after the temperature of a connector fall 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. However, if a connector seal opens at a temperature where liquid or gaseous contaminants have not been frozen, contamination can occur.

500.2.3.4 Chemical Effects

Most contact failures of connectors are induced by film growth at contact points. These films can cause increased contact resistance or open circuit. Such increased resistance can cause higher temperature interfaces, thus increasing the chemical activity. Ions in impurities or contamination in the surface pores of contacts will migrate to the points of highest potential, which are frequently the localized hot spots. Ions interfacing with electrons and other constituents at the points of high chemical activity usually generate nonconducting films. 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.

500.2.3.5 Cycling Effects

The connector plugged to its mate during much of its operational life is characterized by a typical catastrophic failure rate based on the factors described. Many connectors, particularly of the cable type that are repeatedly plugged and unplugged continuously expose the contacts to a fresh supply of local corrosive contaminants. These cycling effects also create the problem of physical wear on the connecting interfaces. Surface contact points become worn making unsymmetrical contacts and sometimes substituting nonconducting films to replace conducting points in the physical interface. The result is increased interface resistance, higher conduct temperature and degradation of the connection. Hence, there is an added failure rate relation between cycling rate of connector contacts and operational life.

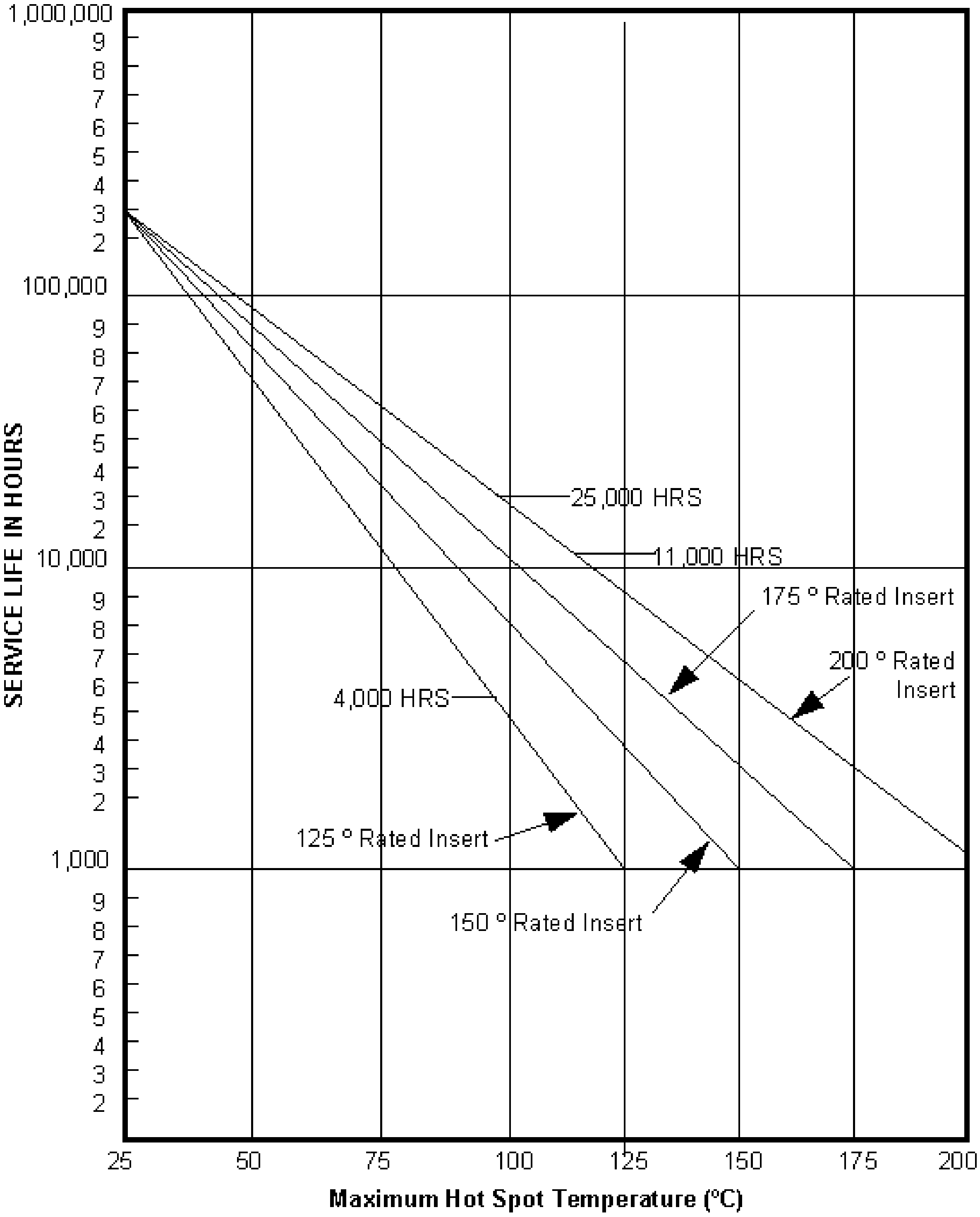

Figure 500.1 -- Service Life Versus Hot Spot Temperature

500.2.3.6 Operation in Parallel

When pins are connected in parallel at the connector to increase current capacity, allow for at least a 25 percent surplus of pins over that required to meet the 60 percent derating for each pin when assuming equal current in each. This is required, since the currents will actually not divide equally due to differences in contact resistance. For example, it would take five Pins, each rated at one amp, to conduct two amps.

500.2.3.7 Protective Measures

All unmated connectors, during shipment, storage or operation, should be kept covered with moisture proof or vapor proof caps. Protective caps specified by military specifications or military standards and designed for mating with specific connectors should be used. Where such protective caps are not available, disposable plastic or metallic caps designed for purpose should be used.

501 Connectors, Cylindrical, General Duty

501.1 MIL-C-5015, Connectors, Electrical, Circular Threaded, "AN" Type

501.1.1 Application Considerations

501.1.1.1 Insulation Resistance

The insulation resistance limits vary with the temperature as shown in Figure 500.2.

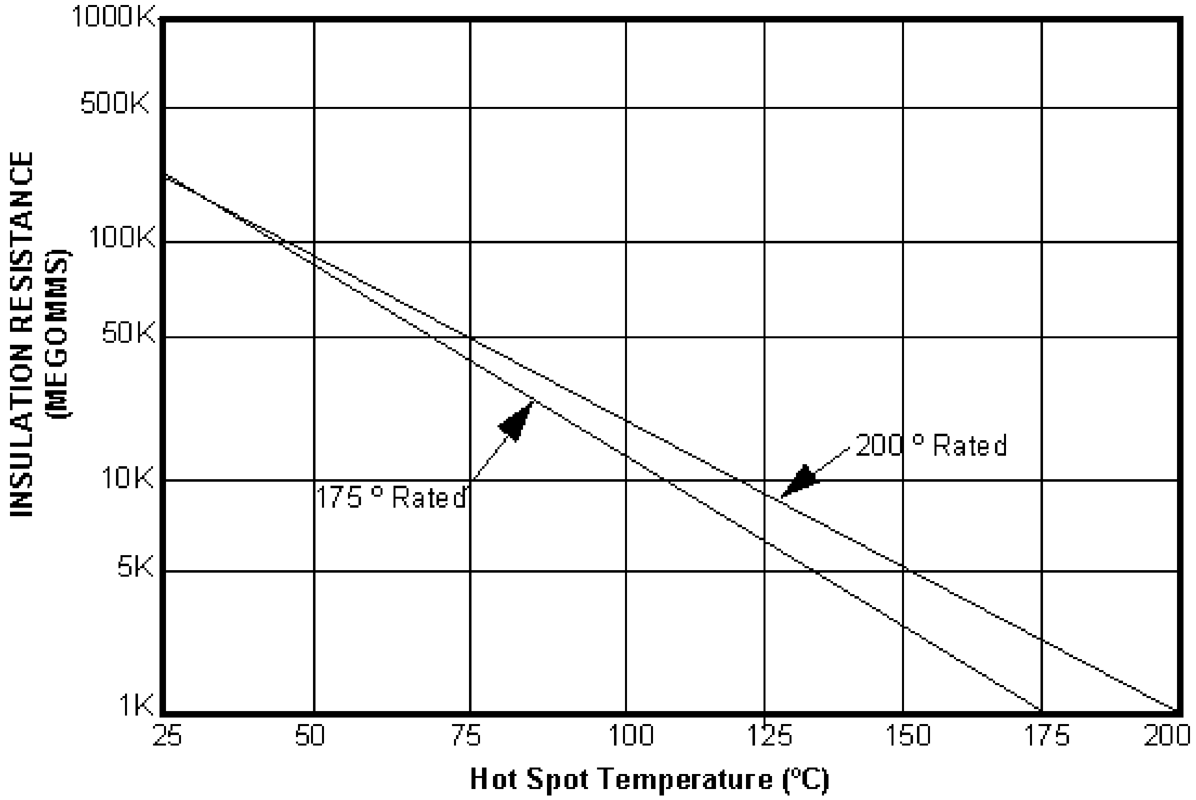

Figure 500.2 -- Insulation Resistance Versus Temperature

501.1.1.2 Service Life

The service life of these connectors varies with temperature as shown in Figure 500.1.

501.1.1.3 Durability (Required by the Specification):

a. ***With Coupling Rings*** -- Counterpart connectors are required to be capable of mating and unmating 100 times at a maximum of 10 cycles per hour with coupling rings attached.

b. ***Without Coupling Rings*** -- Counterpart connectors are required to be capable of mating and unmating 500 times at a maximum rate of 600 cycles per hour with the coupling rings removed.

501.1.2 Application Restrictions According to MIL-STD-1353

a. Type MS3400s shall be used only for shipboard jacketed cable applications.

b. Type MS3450s shall not be used for shipboard jacketed cable applications and classes W and K are only acceptable for hookup wire applications.

501.2 MIL-C-38999, Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect, Environment Resistant, Removable Crimp Contacts

501.2.1 Application Considerations

501.2.1.1 Intended Use

The various configurations of series III and series IV connectors are intended for use as follows:

a. Class F (environment resisting) -- conductive plating.

b. Class K (environment resisting) -- corrosion resistant steel with firewall barrier.

c. Class W (environment resisting) -- corrosion resistant plating.

d. Class Y (hermetically sealed) -- corrosion resistant steel, passivated.

501.2.1.2 Application Restriction According to MIL-STD-1353

Series III and IV connectors shall not be used in Navy shipboard jacketed cable applications. Series III with finish “W” are acceptable for hook-up wire applications.

501.2.1.3 Sealing Plugs

Sealing plugs should be installed in all grommet holes of E and T connectors which do not contain wires.

501.2.1.4 Performance

The tests of mated connectors covered in the dielectric withstanding voltage at altitude tests are overstress tests intended to demonstrate the sealing capabilities of mated connectors. They are not to be taken as indicative of recommended service usage. Operating voltages shall be based upon the applicable test voltages for unmated connectors with suitable allowances for transients, switching surges, and safety factors appropriate to the particular circuit in which the connector is to be used.

501.2.1.5 Contact Size

Connectors containing size 22 and smaller contacts shall not be used for equipment designed for military applications, unless specifically approved by the procuring activity.

501.3 MIL-C-28840, Connectors, Circular Threaded, High Density, High Shock Shipboard, Class D

501.3.1 Application Considerations

501.3.1.1 Application Restriction According to MIL-STD-1353

These connectors are for use with jacket cable in shipboard applications.

502 Connectors, Cylindrical, Heavy Duty

502.1 MIL-C-22992, Connectors, Cylindrical, Heavy Duty

502.1.1 Application Considerations

502.1.1.1 Intended Use of Class C Connectors

Connectors are intended for heavy duty (rough serviced applications for external electrical interconnection of equipments such as shelters, vans, buildings, missile/space launch sites.

502.1.1.2 Intended Use of Class R Connectors

Connectors are intended for heavy duty (rough service) applications in protected enclosures where water-proofing (unmated) or pressurization is not required.

502.2 MIL-C-22992, Connectors, Cylindrical, Heavy Duty

502.2.1 Application Considerations

502.2.1.1 Intended Use of Class L Connectors

Connectors are intended to be used for power connections in the current range of 60 to 200 amperes and will be used only with the heavy duty jacketed cables specified on the applicable insert standard. Reference MIL-STD-255.

503 Connector, Rack and Panel

503.1 MIL-C-24308, Connectors, Electric, Rectangular, Miniature Polarized Shell, Rack and Panel (and Associated Accessories)

503.1.1 Application Considerations

503.1.1.1 Intended Use

Class G connectors are intended for use in nonenvironment. resisting applications where the operating temperature range of -55ºC to 125ºC is experienced.

Class N connectors are intended for use in applications where presence of residual magnetism must be held to low levels to avoid interference with nearby sensitive instrumentation.

Class H connectors are intended for use in application where atmospheric pressures must be contained by the connectors across the wall or panels they are mounted on.

503.2 MIL-C-28731, Connectors, Electrical, Rectangular, Removable Contact, Formed Blade, Fork Type (for Rack and Panel and Other Applications)

503.2.1 Application Considerations

503.2.1.1 Intended Use

These connectors are intended for use in electronic and electrical equipment.

503.3 MIL-C-28748, Connectors, Electrical, Rectangular, Rack and Panel, Solder Type and Crimp Type Contacts

503.3.1 Application Considerations

503.3.1.1 Intended Use

These connectors are intended for use in nonenvironmental applications only.

503.4 MIL-C-28804, Connectors, Electric, Rectangular, High Density, Polarized Center Jackscrew

503.4.1 Application Considerations

503.4.1.1 Intended Use

Class G connectors are intended for use in nonenvironment resisting applications where the operating temperature range of -55ºC to 125ºC is experienced.

Class E connectors are intended for use in environmental resisting applications. Provisions are made for sealing around wire at rear of connectors.

503.5 MIL-C-81659, Connectors, Electrical, Rectangular, Environment Resistant, Crimp Contacts

503.5.1 Application Considerations

503.5.1.1 Intended Use

MIL-C-81659 covers environmental resistant rectangular connectors with one to four inserts per connector.

503.6 MIL-C-83733, Connectors, Electrical, Miniature, Rectangular Type, Back to Panel, Environmental Resisting, 200 Degree C Total Continuous Operating Temperature

503.6.1 Application Considerations

503.6.1.1 Intended Use

MIL-C-83733 covers miniature environmental resisting, 200ºC rectangular connectors. All the types and classes are intermatable under the same shell size.

504 Connectors, Printed Wiring Board

504.1 MIL-C-21097, Connectors, Electrical, Printed Wiring Board, General Purpose

504.1.1 Application Considerations

All characteristics are applicable and no restrictions apply.

504.2 MIL-C-55302, Connectors, Printed Circuit Subassembly and Accessories

504.2.1 Application Considerations

All characteristics are applicable and no restrictions apply.

505 Connectors, Test Point

505.1 MIL-C-39024, Connectors, Electrical; Jacks, Tip (Test Point, Panel or Printed Wiring Type)

505.1.1 Application Considerations

All characteristics are applicable and no restrictions apply.

506 Connectors, Power, General Duty

506.1 WC-596, Connectors, Plug, Receptacles and Cable Outlet, Electrical Power

506.1.1 Application Considerations

All connectors are of the grounding type and of non-armored, dead front construction.

507 Connectors, Radio Frequency, Coaxial

507.1 MIL-C-39012, Connectors, Radio Frequency, Coaxial

507.1.1 Application Considerations

507.1.1.1 Intended Use

MIL-C-39012 covers radio frequency connectors used with flexible RF cables and certain other types of coaxial transmission lines.

508 Sockets, Plug-In

508.1 MIL-S-83502, Socket, Plug-In, Electric Components, Round Style

508.1.1 Application Considerations

508.1.1.1 Intended Use

Intended for use on panel boards, printed circuit boards, and microelectronic components.

508.2 MIL-S-83505, Socket (Lead, Electronic Components)

508.2.l Application Considerations

5082.1.1 Intended Use

Intended use for insertion through mounting boards or panels.

508.3 MIL-S-83734, Socket, Plug-In, Electronic Components

508.3.1 Application Considerations

508.3.1.2 Intended Use

Intended for use on panel boards, printed circuit boards, and microelectronic components.

508.4 MIL-S-12883 Socket, Plug-In, Electronic Components

508.4.1 Application Considerations

508.4.1.1 Intended Use

Intended for plug-in electronic components, such as electron tubes and related electronic devices, plug-in related electronic devices, plug-in capacitors, crystal units, batteries, vibrators, relays, coils, etc.

509 Derating Requirements

When using connectors, current and operating temperature shall be derated according to the maximum allowable derating curves as shown in Figure 500.3.

The voltage between the contacts shall not exceed 25 percent of the dielectric withstanding voltage.

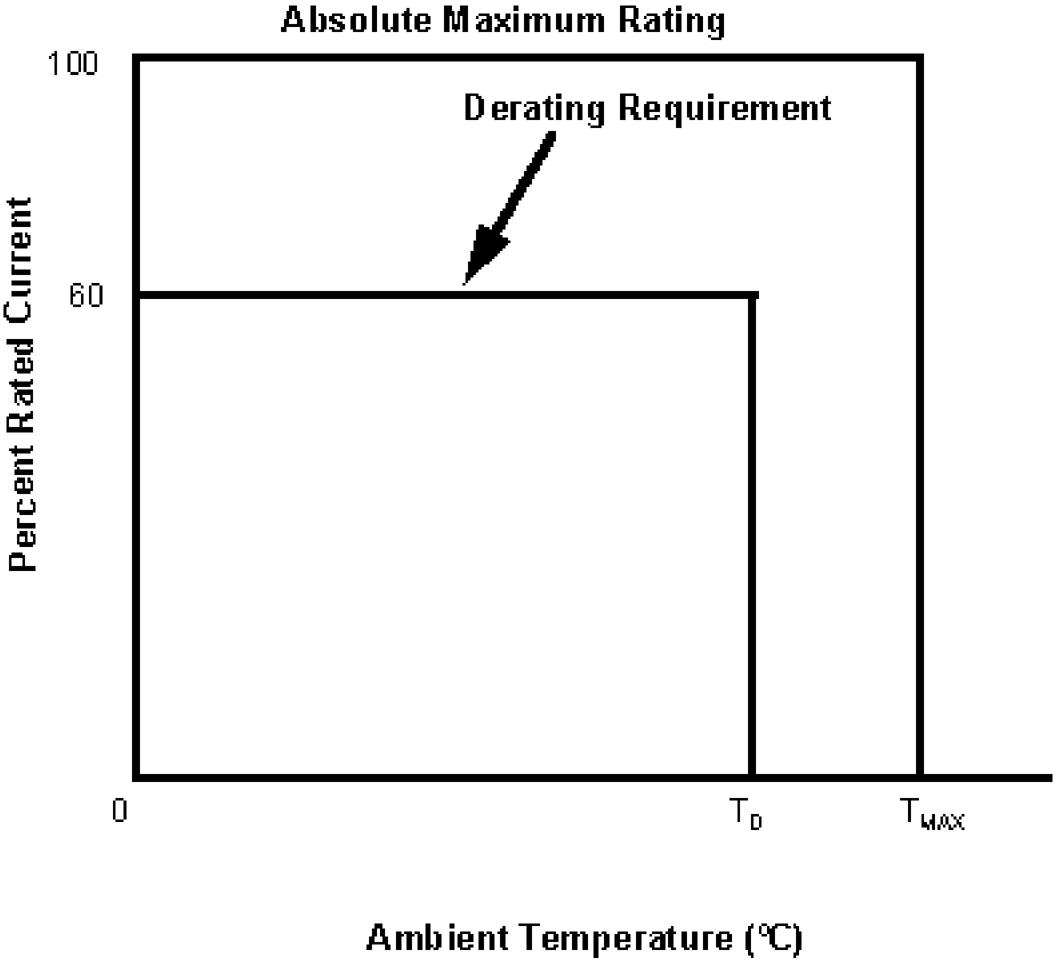

Figure 500.3 -- Maximum Allowable Derating Curve

All Connectors Except Printed Circuit Board Connectors		
Insert Material	T_{MAX}	T_D *
A	250	190
B	200	130

C	120	50
D	120	50
*Temperature Rise of insert Material included.		

Printed Circuit Board	
T_{MAX}	T_D
200	165
**Temperature Rise of Contact included.	

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Section 600 -- Relays

600 Relays

600.1 General Information

A relay is defined 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. Standard relays are specified in MIL-STD-1346. Relays should be selected based upon the function to be performed. Table 600-I summarizes the relay types applicable to different functions, while Section 601 provides narrative details for relay application. Where more than one type of relay can be used in a given application, consideration should be given to cost and availability. Classification of relays can be in accordance with application, by construction, or configuration, or a combination of these categories. These classifications are as discussed below.

600.1.1 Classification by Application

Classifications are of an arbitrary nature, and 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 with 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 may be 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 operating current. The relatively low 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.

600.1.2 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.

Table 600-I. -- Relay Application Data

		Application Specification MIL-R-					
	Relay Function	5757	6106	28750	39016	83726	28776
For Electronic and Communication Type Equipment, General Purpose							
DC Operated		X			X		
AC Operated		X					
Sensitive		X			X		X
Hybrid							
General Purpose							
DC Operated			X				
AC Operated			X				
AC/DC Operated							
No standard part has been established.							
Electromagnetic, ER					X		
Latching DC Operated		X	X		X		
AC Operated			X				
AC/DC Operated			X				
Reed Type		X					
Dry Reed							
Time Delay Type	Electric and Electronic Solid State		No standard part has been established.			X	
Telegraph Relays, Passive, Solid State		No standard part has been established.					
Solid State				X			
Vacuum, High Voltage (DC Coil Operated)		No standard part has been established.					

All the specifications give the part number to M -- specification number -- slash sheet number.
In addition, MIL-R-6106 relays have "MS" numbers, and MIL-R-83726 relays have dash numbers.

Note: A relay contact gap operational requirement of 0.005 minimum opening should be observed as a general application requirement.

The actuating coils may be operated with ac or DC voltage. Relays operated on direct current usually 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. Switching characteristics are controlled by this 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 characteristics 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 limited and at present only single pole devices are available.

f. ***Time-delay***

1. A delay in operate time or 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 results in 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.

In general, relays are used to:

a. Obtain isolation between input and output circuits.

b. Invert the signal sense (from open to closed and vice versa).

c. Increase the number of output circuits (so as to switch more than one load or to switch loads from different sources)

d. Repeat signals

e. Switch loads of different voltage or current ratings

f. Retain an input signal

g. Interlock circuits

h. Provide remote control

600.2 Application Considerations

600.2.1 Switching

Circuits to be switched shall be designed to minimize stresses on the relay contacts.

600.2.2 ARC Suppressors

ARC suppression techniques should be used to protect relay contacts. Arc suppression circuitry (e.g., diodes) should be mounted externally to the relay package.

600.2.3 Reliability Considerations

Solid state relays are preferred over electromechanical relays. Redundant configurations should be used when high reliability is required. Contacts should be operated in parallel for redundancy only and never to increase the current rating of the relay contacts. Contact life is a central concern relative to overall reliability. With the exception of solid state units, relays are electromechanical devices and, therefore, 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 currents, or from high voltage spikes generated 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. Such failures are often intermittent and difficult to verify. Causes may be nonmetallic or gaseous contamination, which periodically deposits itself on contacts, causing an open condition; or metallic particles which cause shorted conditions or block movement of mechanical parts. Contamination can be significantly reduced by proper 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.

In the event of failures attributed to vendor workmanship, timely corrective action can significantly reduce this type of failure.

Engineering selection of the proper relay for an application is the most significant factor of relay reliability.

600.2.4 Misapplications

Misapplication of relays will result in reduced reliability. The following, taken from MIL-STD-1346, is a listing of typical relay misapplications:

a. Improperly using existing military specifications or using the incorrect relay military specification.

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 redundancy in the low level or minimum current (contamination test current) areas.

c. Circuit transient surges. Circuit designers shall be careful not to expect relays to handle circuit transient surges in excess of their ratings. It should be noted that surge currents greater than ten times the steady state currents can result when switching inductive, capacitive and lamp loads. Protection devices (such as transient suppression diodes) should be used to limit these surges or a relay rated higher than the surge current should be used.

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, relays designed for low-level applications should not be used at low level loads after having been tested or used for a short period of time at high level loads. A cold filament lamp draws very high currents (between 3 and 10 times steady-state value) until warmed up. Contacts used for switching lamps should be able to withstand such current surges without the possibility of welding contacts.

e. Using relays at higher voltages than those for which they were designed, for example, switching 300 volt power supplies with relays rated at 115 volts maximum.

f. Contact ratings with grounded case. Some relays employing a grounded case have small internal spacing, or lack arc barriers. In such cases, contact ratings should be derated more than in the ungrounded case mode of operation when switching in excess of 40 volts ac or dc. Typically, the maximum ac rating of a nominally rated 28 Vdc, 2 amp resistive relay, is of the order of 0.150 ampere. Switching high voltage with the relay case ungrounded results in a potential personnel hazard.

g. Transferring loads between unsynchronized power supplies with inadequately rated contacts. When a load is switched, the voltages can range from being in phase to 180_ out of phase; therefore, the relay contact voltage can vary from zero volts to twice 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 volts single phase ac) in 115/200 volt 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 reverse motors, 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. Only power relays rated for "plugging" and reversing service should be utilized in these applications.

j. Using relays with no established minimum current (contamination test current) capabilities. It should not be assumed that because a relay is used in an application considerably below its rated contact load that the consideration of minimum current (contamination test current) capability can be ignored; this is especially true if there is no established level of minimum current (contamination test 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, at 28 volts or higher.

l. Effects of ambient temperature on coil overdrive. Many users do not realize that more power is required to operate a relay at elevated temperatures. A coil operated relay is a current device (ampere-turns). Temperature increases coil resistance at the rate of 0.004 ohm/ohm/ºC due to the temperature coefficient of copper. Therefore, with a given voltage applied to a relay coil, overdrive decreases at elevated temperatures; if this is not taken into account, misapplication occurs. When rated voltage is specified, an ambient temperature is usually also specified, the user should consider the maximum ambient temperature condition and the effect upon the voltage that is supplied.

m. Relay race involves conditions where one relay must operate prior to another in separate drive circuits. Relay race circuits should be avoided, but where they must be used ambient temperature, drive power, operate and release times, coil suppression circuitry, and wear consideration should be carefully considered.

n. A problem is encountered when a relay coil is operated from a slowly rising current. When a triggering threshold is reached, the relay operates. Back electromotive forces (EMFs) are produced when the armature closes to the pole face. This voltage being opposite in polarity to the driving voltage causes the relay to release and then reoperate. This chatter condition continues until a sufficient amount of drive current is available to overcome the back EMFs.

o. Relays rated for 400 Hz only, shall not be used at 60 Hz.

p. Using relays to switch inductive loads. While ac inductive circuit requirements and relay capabilities can be properly matched in terms of current, voltage, frequency, and power factor, no such positive comparison method exists for DC inductive circuits. Thus, special care should be exercised in selecting relays to switch DC inductive loads.

q. Using coil transient suppression relays where suppression is not required. Suppressing coil transients can affect load switching capability and relay life. Using maximum possible suppression will increase relay drop-out time. Increased drop-out time can reduce the amount of current that can be switched and the relay life. Increased drop-out time can also adversely offset relay logic circuits.

r. Relays should be located and mounted to minimize the probability of contact chatter due to shock and vibration. The shock from pyrotechnic sources is a significant problem to relays; this can be avoided by the use of solid-state relays.

s. Contacts should never be operated in series to "increase voltage rating."

t. Relays which are not designed specifically for load transfer applications should not be used for that purpose.

600.3 Derating

Relays shall be derated according to Table 600-II.

600.4 Relay Designations

Two methods used in the specifications of relays are:

a. Military standard

MS27400	-19	X
Military standard number	Dash number	Failure rate when specified

b. Military specification (only MIL-R-39016 is included in MIL-STD-975)

MS27400	/9	–058	X
Military specification (only MIL-R-39016 is included in MIL-STD-975)			
M39016 Military specifications	/9 Slash sheet	–058 Dash number	X Failure rate

number			

600.4.1 Temperature Class

The temperature class is identified by a single letter according to Table 600-III.

600.4.2 Shock

Shock is identified by a single digit according to Table 600-IV.

600.4.3 Vibration Characteristics

Vibration characteristics are identified by a single digit according to Table 600-V.

600.4.4 Terminal

The style of the terminal is identified by a single or double letter according to Table 600-VI.

Table 600-II. -- Derating Factors

Parameter	Max. % of the Resistive Load Rated Value
Contact Current (continuous)	60 -- Capacitive load 60 -- Resistive load 40 -- Inductive load 20 – Motor 10 -- Filament (Lamp)
Contact Current (surge)	80
Coil Energize Voltage	110 maximum
Coil Dropout Voltage	90 minimum
Vibration	75 (including Q of mounting)
Maximum Derated Ambient Temperature	Limit to 80% of maximum

Table 600-III. -- Temperature Class

Symbol	Operating Ambient Temperature Range (ºC)

A	-55 to + 85
B	-65 to +125
C	-65 to +200
D	-55 to + 71
E	-65 to + 85
F	0 to + 70
G	-70 to +125
H	-70 to +200
J	-55 to +125

Table 600-IV. -- Shock

Symbol	Conditions Test	Applicable Test Methods of MIL STD-202
1	A (50G)	213
2	B (75G)	213
3	C (100G)	213
5	--	207 (high-impact)
6	(200G)	213 (6 ±1 ms pulse duration)
7	D (500G)	213
8	E (150G)	213 (11 ±1 ms half-sinewave)
9	F (1100G)	213
Note:	Symbols 1, 2, and 3 replace 15, 30, and 50G of Methods 202 and 205 of MIL-STD-202.	

Table 600-V. -- Vibration Characteristics

Symbol	Acceleration Value	Vibration Condition(Hertz)
1	02 (G)	10 -500
2	“.060 dble ampltd”	10 -55
3	10 (G)	10 -500
4	10 (G)	10 -- 1,500
5	15 (G)	10 -- 2,000
6	20 (G)	10 -- 2,000
7	20 (G)	10 -- 3,000
8	30 (G)	10 -- 2,000
9	30 (G)	10 -- 3,000
10	50 (G)	10 -- 3,000
11	5 (G)	10 -- 2,000
12	10 (G)	10 -- 2,000
13	10 (G)	55 -- 2,000
14	“.060 dble ampltd”	10 -- 80

Note: Use .060 double amplitude whenever it is less than the curve “G” level.

600.4.5 Failure Rate Level

The specified failure rate level is identified by a single letter according to Table 600-VII. Only ER level “P” or higher shall be used.

Table 600-VI. -- Terminal Style

Symbol	Style of Terminal
L	Lug (solder hooks)
SKP	Socket pin/plug in

STUD	Stud
SP	Wirelead, Solder Pin
WL	Wire Lead
.500	Lead (TO-5)
.187	Lead (TO-5)

Table 600-VII. -- Failure Rate Level (Established at 90% Confidence Level For Qualification and a 60% Confidence Level for Maintenance of Qualification)

Symbol	**Failure. Rate Level % 10,000 Operations)**
L	3.0
M	1.0
P	0.1
R	0.01
S	0.001

601 Relays, Electrical, for Electronic and Communication Type Equipment

601.1 DC Operated

This section covers relays with DC voltage rated coils and contacts nominally rated up to and including 10 amperes. The applicable military specifications for these relays are MIL-R-5757 and MIL-R-39016 having the following characteristics:

a. Duty Cycle -- Continuous

b. Altitude -- Up to 70,000 feet

c. Enclosure -- Hermetically sealed

For standard part numbers and individual relay characteristics see MIL-STD-1346.

601.2 AC Operated

This section covers relays with ac voltage rated coils and contacts nominally rated up to and including 10 amperes. The applicable military specification for these relays is MIL-R-5757 having the following characteristics:

a. Duty Cycle -- Continuous

b. Altitude -- Up to 70,000 feet

c. Enclosure -- Hermetically sealed

d. Pickup Voltage -- 90 Vac (max) over specified temperature range

e. Dropout Voltage -- 30 Vac (max) over specified temperature range

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

601.3 Sensitive

This section covers relays designed to operate with an input coil power of 100 milliwatts or less. The applicable military specifications for these relays are MIL-R-5757 and MIL-R-39016 having the following characteristics:

a. Duty Cycle -- Continuous

b. Altitude -- Up to 70,000 feet

c. Enclosure -- Hermetically sealed

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

601.4 Hybrid

This section covers relays that use a combination of solid state circuitry and an electromechanical relay to perform the switching function. The applicable military specification for these relays is MIL-R-28776 having the following characteristics:

a. Duty Cycle -- Continuous

b. Altitude -- Up to 70,000 feet

c. Enclosure -- Hermetically sealed

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

601.5 MIL5757, Relays, Electrical (for Electronic and Communication Type Equipment)

601.6 MIL28776, Relays, Electrical for Electronic and Communication Type Equipment, Hybrid

601.7 MIL39016, Relay, Electromagnetic, Established Reliability

601.7.1 Quality Level

Only ER Level “P” or higher shall be used

602 Relays, Electric, General Purpose

602.1 DC Operated

This section covers DC voltage rated relays nominally rated for 5 amperes and up. The relays are capable of meeting the electrical and environmental requirements when mounted directly to a structure. The applicable military specification for these relays is MIL-R-6106 having the following characteristics:

a. Duty Cycle -- Continuous

b. Rated Coil Voltage -- 28 Vdc

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

602.2 AC Operated

This section covers AC voltage rated relays nominally rated for 5 amperes and up. The relays are capable of meeting the electrical and environmental requirements when mounted directly to a structure. The applicable military specification for these relays is MIL-R-6106 having the following characteristics:

a. Duty Cycle -- Continuous

b. Rated Coil Voltage -- 115 Vac, 400 Hz

c. Enclosure -- Hermetically sealed

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

602.3 AC/DC Operated

This section covers relays with ac and DC voltage rated coils and contacts rated 5 amperes and up. These relays are capable of meeting the electrical and environmental requirements when mounted directly to the structure.

Note: At this time, no military specifications are established.

602.4 MIL6106, Relays, Electromagnetic

603 Relays, Latching

603.1 DC Operated

This section covers relays with DC voltage rated coils and contacts that latch in the energized or deenergized position, or both positions, until reset electrically. The military specifications covering these relays are MIL-R-5757, MIL-R-6106 and MIL-R-39016 having the following characteristics:

a. Duty Cycle -- Continuous

b. Enclosure -- Hermetically sealed

c. Operating Temperature Range -- -65ºC to 125ºC

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

603.2 AC Operated

This section covers relays with ac voltage rated coils and contacts that latch in the energized or deenergized position, or both positions, until reset electrically. The military specification covering these relays is MIL-R-6106 having the following characteristics:

a. Duty Cycle -- Continuous

b. Enclosure -- Hermetically sealed

c. Rated Coil Voltage -- 115 Vac, 400 Hz

d. Operating Temperature Range -- -65ºC to 125ºC

e. Shock -- 3 (see Table 600-IV)

f. Vibration -- 4 (see Table 600-V)

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

603.3 AC/DC Operated

This section covers relays with ac/dc voltage rated coils and contacts that latch in the energized (DC) or deenergized (AC) position, or both positions, until reset electrically. The military specification covering these relays is MIL-R-6106 having the following characteristics:

a. Duty Cycle -- Continuous

b. Enclosure -- Hermetically sealed

c. Operating Temperature Range -- -65ºC to 125ºC

d. Shock -- 3 (see Table 600-IV)

e. Vibration -- 4 (see Table 600-V)

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

604 Relays, Reed (Dry) Type

604.1 Dry Reed

This section covers relays consisting of one or more reed switch capsules and one or more coils. The military specification for these relays is MIL-R-5757 having the following characteristics:

a. Duty Cycle -- Continuous

b. Enclosure -- Sealed

c. Shock -- 3 (see Table 600-IV)

For standard relays and individual relay characteristics, see MIL-STD-1346.

605 Relays, Time Delay

605.1 Electric and Electronic

This section covers time delay relays in which the specified time delay interval is obtained through the use of electric or electronic circuitry. The military specification for these relays is MIL-R-83726 having the following characteristics:

a. Duty Cycle -- Continuous

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

605.2 Solid State

This section covers time delay relays in which the specified time delay interval is obtained through the use of solid state electronic circuitry.

Note: At this time, no military specifications are established for these relays.

605.3 MIL83726, Relays, Time Delay, Hybrid and Solid State

605.3.1 Classification

Time delay relays covered by this section consist of the following types and classes:

a. ***Type*** -- The type is identified as follows:

I-Time delay on operate.

IIA-Time delay on release (separate control and power terminals).

IIB-Time delay on release (true).

III-Interval timer.

IV-Repeat cycle timer.

V-Time sequence as specified.

b. ***Class*** -- The class is identified as follows:

A-Hybrid (integral electromagnetic relay qualified to MIL-R-5757 or MIL-R-39016).

B-Hybrid (integral electromagnetic relay qualified to MIL-R-6106).

C-Solid state.

D-Hybrid (integral electromagnetic relay not qualified with contact ratings 5 amperes or lower).

E-Hybrid (integral electromagnetic relay not qualified with contact ratings 5 amperes or higher).

605.3.2 Ratings

Time delay relays with electromechanical relay output and with contact ratings 10 amperes or greater shall be class B or class E.

606 Relays, Telegraph

606.1 Passive, Solid State

This section covers solid state polar relays for use in telegraph circuits and associated equipment.

Note: At this time, no military specifications are established for these relays.

607 Relay, Solid State

607.1 Solid State

This section covers relays utilizing only semiconductor and electrical passive circuit devices. The military specification covering these relays is MIL-R-28750.

607.2 MIL28750, Relay, Solid State

608 Relays, Vacuum, High Voltage

608.1 DC Coil Operated

This section covers relays, vacuum, high voltage DC coil operated.

Note: At this time, no military specifications are established for high voltage, vacuum, relays.

Next Section

Previous Section

Chapter I -- Requirements

1. Scope

This document establishes part derating requirements, minimum quality levels and analysis information for the reliable application of parts in electronic equipment. This document provides information that supplements a parts control program. Requirements for selecting standard parts, approving nonstandard parts and other parts control program requirements are defined in MIL-STD-965.

Chapter I identifies part quality levels and part derating requirements defined in greater detail in Chapter II.

Chapter II contains part application guidelines and detailed derating requirements for commonly used standard part types.

The appendices contain information on general topics applicable to parts applications and reliability. The appendices are intended to aid in the understanding of the requirements specified in Chapters I and II.

2. Reference Documents

The documents specified herein on the issue in effect on the date of invitation for bid or request for proposal, form a part of the requirements of Section 3 to the extent they are specified. These documents and other documents are listed in Appendix G. In the event that advancing technology may supersede some of the requirements of this manual, resolution should be obtained from the procuring activity.

3. Requirements

The requirements of this chapter are applicable as specified in the contract. When this document is cited in a contract any deviation from the requirements specified in Section 3 herein shall require approval by the Procuring Activity.

3.1 Parts Requirements

3.1.1 Control Program

If required by contract, the contractor shall implement a MIL-STD-965 parts control program.

3.1.1.1 Government Furnished Baseline (GFB)

The GFB is intended to support the DoD Standardization and Parts Control Programs by providing listings of preferred parts for use in military electronic/electrical systems. The GFB electronics parts list is comprised of those parts and part types which have been evaluated by the Military Parts Control Advisory Group (MPCAG) of the Defense Electronic Supply Center (DESC) and subsequently recommended for use. Essentially the GFB is a list of approved standard parts for design selection, and should be specified early in the acquisition process at the solicitation point. When contractually approved, those parts selected from the GFB can be added to the PPSL without further evaluation. The purpose and goal of the GFB is to allow for minimizing the number of part submittals, reduction of procurement problems, and to provide standardization guidance. The GFB currently consists of three "sub" baselines:

GFB-01 This baseline is used primarily by AIR FORCE and ARMY activities for both airborne and ground applications. This baseline satisfies the requirements of MIL-STD-454 and MIL-E-5400.

GFB-03 This baseline is used primarily by NAVAL AIR SYSTEMS COMMAND for airborne applications, taking into account shipboard environments. This baseline satisfies the requirements of MIL-STD-454, MIL-E-5400, and MIL-E-16400.

GFB-NAVSEA This baseline is used primarily by NAVAL SEA SYSTEMS COMMAND for shipboard, submarine, and other equipments which are either exposed to or immersed in salt water. This baseline satisfies the requirements of MIL-STD-454 and MIL-E-16400.

3.1.2 Part Quality Levels

3.1.2.1 Passive Parts

Passive parts shall be selected from Established Reliability (ER) military specifications. They shall meet, (unless specified otherwise by contract) as a minimum, an ER failure rate level of P or higher (i.e., R or S). As an exception, parts procured to Weibull failure distributions (i.e., solid tantalum capacitors (MIL-C-39003)) shall be ER failure rate level (Weibull) of B or higher (i.e., C or D). In the event that parts are unavailable at the minimum failure rate level, then the contractor shall use the highest quality level part available. The selection of a lower quality level part will normally require nonstandard part approval from the Procuring Activity in accordance with 3.1.3. Lower quality level parts should not be used in the design, development, or production of any electronic hardware and equipment if there are direct ER replacements available.

3.1.2.2 Discrete Semiconductors

Discrete semiconductors shall be selected in accordance with the provisions of MIL-STD-965 and MIL-STD-454, Requirement 30. Quality level shall be in accordance with MIL-STD-454, Requirement 30. Lower quality level semiconductors are considered nonstandard and shall be treated as such. To use a nonstandard semiconductor, the contractor shall: (1) justify the selection of the lower quality level part to the Procuring Activity, (2) upgrade screen the part to the JANTX screening requirements of MIL-S-19500, (3) receive nonstandard part approval from the Procuring Activity in accordance with 3.1.3, and (4) mark the part with a contractors part number identifying it as nonstandard.

3.1.2.3 Microcircuits

Microcircuits (and by extension, hybrid circuits) shall be selected in accordance with the requirements of MIL-STD-965 and MIL-STD-454, Requirement 64. Quality level shall be in accordance with MIL-STD-454, Requirement 64. Lower quality level microcircuits and hybrid circuits are considered nonstandard and shall be treated as such. To use a nonstandard microcircuit or hybrid the contractor shall: (1) justify the selection of the lower quality level part to the Procuring Activity, (2) upgrade screen the part to MIL-STD-883 Class B requirements, (3) receive nonstandard part approval from the Procuring Activity in accordance with 3.1.3, and (4) mark the part with a contractors part number identifying it as nonstandard.

3.1.2.4 Hybrid Microcircuits

Hybrid microcircuits shall be selected in accordance with the requirements of MIL-STD-965 and MIL-H-38534. Quality level shall be determined by the contract and shall consist of one of the three options provided by MIL-H-38534, paragraph 3.4.

3.1.3 Nonstandard Part Requirements

Unless otherwise specified in the contract, the use of nonstandard parts shall require approval by the Procuring Activity. The contractor shall provide documentation, justification, and qualification provided in accordance with MIL-STD-965, Parts Control Program.

3.1.3.1 Additional Definitions of Nonstandard Parts

A nonstandard part is a part which does not meet the minimum quality levels given in 3.1.2.1, 3.1.2.2, and 3.1.2.3. In addition, a nonstandard part is further defined as:

a. ***Nonstandard Application*** -- Use of a part in an application where its specification does not apply (e.g. a tantalum capacitor used at a frequency outside its recommended operation frequency). In these cases the contractor shall provide: (1) justification for the use of that part and (2) data showing that the part will perform the desired circuit functions without degradation to its reliability over the expected life of the system. For further details refer to MIL-STD-965.

b. ***Nonstandard Parameters*** -- Part selection or use in an application where performance is dependent on a characteristic or parameter not controlled by its military specification. In these instances the contractor shall provide: (1) justification for using the part and (2) proof that the uncontrolled parameter will be maintained. For further details refer to MIL-STD-965.

3.1.3.2 Derating Requirements for Nonstandard Parts

A nonstandard part shall be derated the same as its nearest equivalent standard military part. For example, a nonstandard chip tantalum capacitor may be required in a circuit because of size and space constraints. The derating requirements for this part would be the same as its nearest equivalent military standard part. This would be a MIL-C-55365 tantalum capacitor.

Nonstandard part specifications should be compatible with the standard part specifications (i.e. the parameters of each part should be measured using the same methods). The derating requirements of this manual are based on military standard parts. Manufacturer's catalog ratings for nonstandard parts should be carefully reviewed. The contractor should be able to demonstrate, by cross-references and/or test data, that the ratings are compatible.

3.1.4 Stress Screening

An inherent and necessary component of Navy Quality and Reliability programs is the provision for latent defect detection, identification, correction-as-to-cause, and recurrence control. The use of Environmental Stress Screening (ESS) of parts, modules, units-of-assembly, or systems is used to detect and identify latent defects in an effort to improve field reliability as well as to reduce production, operational, and maintenance costs. Although the primary focus of this manual is the provision of derating requirements and criteria, a brief synopsis of Navy stress screening rationale, policy, and summary requirements is presented in this section as an adjunct program effort to achieve reliability and quality goals and requirements.

ESS is a term which has evolved to encompass an overall approach of applying electrical and/or environmental stress in such a way as to accelerate the occurrence of any latent defects to the point of detection. ESS is considered as a dynamic manufacturing process in which specific procedures are adjusted, based on screening results, to optimize defect detection and subsequent corrective action. Navy policy is that development and production contracts for all mission essential electronic hardware will provide for requirements for stress screening and such screening shall be documented and integrated with in-process inspection and process control procedures. ESS program requirements and details are provided by other Navy publications, particularly NAVSEA TE000-AB-GTP-020 "Environmental Stress Screening Requirements and Application Manual for Navy Electronic Equipment."

3.2 Derating

Parts identified in Table I and similar part types shall be derated electrically and thermally in accordance with Table I.

The derating requirements in Table I and other related sections are based on ambient temperatures (i.e. the temperature of the air surrounding the part). However, the individual contractor's design or thermal analysis may lend itself better to use case, part, or junction temperatures. The contractor may convert the derating requirements from ambient to case, part, or junction temperature, but the original derating parameters must remain intact. Also, if the contractor converts a table or graph it must be documented and supplied with any derating deliverable data, as required by the contract DD 1423.

3.3 Design for Optimum Life

Designing for optimum life should be an integral part of any design process. The most reliable method of increasing the life of a part is to decrease the stress on that part. Stress is the primary cause of part failures. Therefore, the contractor should perform electrical stress analyses as an integral component of the design process. Such analyses can be aided and expedited by use of MIL-HDBK-251 **"Reliability Design Thermal Applications."** Several examples of such analysis are provided by Appendices A and B.

Mechanical stress analysis should also be conducted on designed structural components. One reference for mechanical stress analysis is **"Handbook of Reliability Prediction Procedures for Mechanical Equipment"** U.S. Army TROSCOM Belvoir Research and Development Center (in preparation). Another is the "Nonelectronic Reliability Notbebook (RADC-TR-69-458)" by Reliability Analysis Center of the Rome Air Development Center.

4. Quality Assurance Provisions

4.1 Responsibility

When specified in the contract, the contractor shall be responsible for the performance of such analyses and tests as may be required to verify that the derating requirements of this contract have been met. The procuring activity reserves the right to perform such tests and any analyses considered necessary to ensure that the design meets the requirements set forth herein.

4.2 Parts Derating Verification Test

Part thermal and electrical derating shall be verified through test by actual measurement of part stress levels and part ambient temperatures. These measurements shall be performed on at least 5 percent of equipment parts. Fifty percent of the candidate parts shall be those having the highest power dissipation in the equipment. The other 50 percent of the candidate parts shall be randomly selected. Should the verification test demonstrate that the derating requirements are not met (i.e., all parts do not meet temperature and electrical derating requirements), corrective action shall be implemented and the test repeated on different parts (i.e., 50 percent of parts having the next highest power dissipation and 50 percent new randomly selected parts).

5. Notes

5.1 Intended Use

This document is intended to facilitate the application of electrical and electronic parts in military systems and equipments in such a manner as to optimize reliability and life cycle costs.

5.2 Definitions

Terms used herein shall be interpreted in accordance with the definitions of MIL-STD-721 unless otherwise specified herein.

5.2.1 Derating

Derating is the application of electrical and electronic parts in such a manner that the actual worst case electrical and thermal stresses are less than the parts design maximum ratings.

5.2.2 Electrical and Electronic Part

An electrical active or passive component, a microcircuit, or a discrete semiconductor.

5.2.3 Rated Stress

The maximum stress for which a part is specified to withstand. The ratings of most parts decrease as the operating temperature is increased.

5.2.4 Application

The method in which an electrical or electronic part is used, which influences its predicted failure rate as well as the effect of its possible failure modes.

5.2.5 Stress

Physical or electrical forces imposed on the electrical or electronic part, such as temperature, current, voltage, power dissipation, etc., which affect part failure rate.

5.2.6 Stress Ratio

The numeric ratio between the applied stress and the maximum rated stress for a given parameter, e.g., applied voltage divided by rated voltage.

Table I-I. Parts Derating Requirements for Resistors

			Electrical	
Part Type	**MIL-SPEC (Style)**	**Parameter**	**Max. % of Rated Electrical Stress**	**Maximum Derated Ambient Temp. (°C)**
Fixed Wirewound (Power Type)	MIL-R-26 (RW)	Power	See derating requirements	See derating requirements
Wirewound(Power Type Chassis Mounted)	ML-R-18546(RE)	Power	See derating requirements	See derating requirements
Variable Composition	MIL-R-94 (RV)	Power	See derating requirements	See derating requirements
Wirewound (Low Operating Temp)	MIL-R-19 (RA)	Power	See derating requirements	See derating requirements
Wirewound (Power Type)	MIL-R-22 (RP)	Power	See derating requirements	See derating requirements
Wirewound, Precision	MIL-R-12934 (RR)	Power	See derating requirements	See derating requirements
Wirewound, Semiprecision	MIL-R-39002 (RK)	Power	See derating requirements	See derating requirements
Wirewound *(Adjustment type)*	MIL-R-27208 (RT)	Power	See derating requirements	See derating requirements

Nonwirewound	MIL-R-22097 (RJ)	Power	See derating requirements	See derating requirements
Nonwirewound	MIL-R-23285 (RVC)	Power	See derating requirements	See derating requirements
Nonwirewound,	MIL-R-39023 (RQ)	Power	See derating requirements	See derating requirements
Fixed, (ER Composition, Insulated	MIL-R-39008 (RCR)	Power	See derating requirements	
Film	MIL-R-55182 (RNR)	Power	See derating requirements	See derating requirements
Wirewound (Accurate)	MIL-R-39005 (RBR)	Power	See derating requirements	See derating requirements
Wirewound (Power Type)	MIL-R-39007 (RWR)	Power	See derating requirements	See derating requirements
Film (Insulated)	MIL-R-39017 (RLR)	Power	See derating requirements	See derating requirements
Wirewound(Power Type, Chassis Mounted)	MIL-R-39009 (RER)	Power	See derating requirements	See derating requirements
Film, Chip	MIL-R-55342 (RM)	Power	See derating requirements	See derating requirements
Variable, (ER) Wirewound (Lead Screw Actuated)	MIL-R-39015 (RTR)	Power	See derating requirements	See derating requirements
Nonwirewound (Lead Screw(Actuated)	MIL-R-39035 (RJR)	Power	See derating requirements	See derating requirements
Special Networks, Fixed, Film	MIL-R-83401 (RZ)	Power	See derating requirements	See derating requirements

Table I-II. Parts Derating Requirements for Capacitors

			Electrical	
PART TYPE	**MIL-SPEC**	**Para meter -**	**Max. % of Rated Electrical**	**Maximum Derated**

	(Style)		**Stress**	**Ambient Temp. (°C)**
Ceramic Dielectric Fixed, Temperature Compensating, ER	MIL-C-20 (CCR)	Voltage	See derating requirements	See derating requirements
Fixed, Chip, Ceramic dielectric ER	MIL-C-55681 (CDR)	Voltage	See derating requirements	See derating requirements
Fixed, General Purpose, ER	MIL-C-39014 (CKR)	Voltage	See derating requirements	See derating requirements
Variable	MIL-C-81 (CV)	Voltage	See derating requirements	See derating requirements
Gas or Vacuum Dielectric Variable, Ceramic Envelope	MIL-C-23183(CG)	Voltage	See derating requirements	See derating requirements
Glass Dielectric Variable(Piston Type, Tubular Trimmer)	MIL-C-14409 (PC)	Voltage	See derating requirements	See derating requirements
Fixed, ER	MIL-C-23269 (CYR)	Voltage	See derating requirements	See derating requirements
Electrolytic Fixed, Tantalum Solid Electrolyte, ER	MIL-C-39003 (CSR)	Voltage Reverse Voltage Ripple Current	See derating requirements 2% of the maximum rated DC voltage. 70	See derating requirements
Fixed, Tantalum Chip, ER	MIL-C-55365 (CWR)	Voltage Reverse Voltage Ripple Current	See derating requirements 2% of the maximum rated dc voltage	See derating requirements

			70	
Fixed, Tantalum, Nonsolid Electrolyte, ER	MIL-C-39006 (CLR)	Voltage Reverse Voltage Ripple Current	See derating requirements 2% of the maximum rated dc voltage. 70	See derating requirements

ELECTRICAL

PART TYPE	MIL-SPEC (Style)	PARAMETER	MAX % OF RATED ELECTRICAL STRESS	MAXIMUM DERATED AMBIENT TEMP.
Fixed, Aluminum Oxide, Non ER, ER	MIL-C-39018 CU/CUR)	Voltage Reverse Voltage‘ Surge Voltage	See derating requirements 2% of the maximum rated DC voltage. 60	See derating requirements
Mica Dielectric Fixed, ER	MIL-C-39001 (CMR)	Voltage	See derating requirements	See derating requirements
Paper, Plastic, Paper-Plastic Dielectric				
Fixed, ER	MIL-C-19978 (CQR)	Voltage	See derating requirements	See derating requirements
Fixed, Metallized DC and AC, ER	MIL-C-39022 CHR)	Voltage	See derating requirements	See derating requirements
Fixed, Supermetallized DC, AC, or DC and AC, ER	MIL-C-83421 (CRH)	Voltage	See derating requirements	See derating requirements

Table I-III. Parts Derating Requirements for Semiconductors

Electrical

Part Type	MIL-SPEC (Style)	Parameter	Max. % of Rated Electrical Stress	Maximum Derated Ambient Temp. (°C)

Diodes	MIL-S-19500	Power	See derating requirements	See derating requirements
		Forward Current (Continuous)	50	
		Current Surge	70	
		Inverse Voltage	65	
		Transient Voltage	80	
Transistors	MIL-S-19500	Power	See derating requirements	See derating requirements
		Forward Current (Continuous)	70	
		Forward Current (Surge)	75	
		Breakdown (Reverse Junction) Voltage	70	
Thyristors	MIL-S-19500	Power	See derating requirements	See derating requirements
		Current (Surge)	70	
		Forward Blocking Voltage	50	
		Turn-off Time	200 Minimum	
Opto-Electronic	MIL-S-19500/ MIL-M-38510	Power		50
		Forward Continuous Current		50
		Junction Temperature		80°C

Table I-IV. Parts Derating Requirements for Microcircuits

Electrical

Part Type	MIL-SPEC (Style)	Parameter	Max. % of Rated Electrical Stress	Maximum Derated Ambient Temp. (°C)
Linear Hermetically sealed micro- circuits except voltage regulators	MIL-M-38510	Power	See derating requirements	See derating requirements
		Output Current (Continuous)	70	
		Output Current (Surge)	60	
		Input Voltage(Signal)	75	
		Supply Voltage (Surge)	80	
		Supply Voltage	Do not exceed mfg. nominal rating.	
Hermetically sealed voltage regulators	MIL-M-38510	Power	See derating requirements	See derating requirements
		Output Current (Continuous)	75	
		Output Current (Surge)	60	
		Input Voltage (Signal)	75	
		Output Voltage (Surge)	80	
		Supply Voltage	Do not exceed mfg. nominal rating.	

		Power	See derating requirements page 400-19	See derating requirements
Nonhermetically sealed micro- on page 400-19. circuits except voltage regulators	MIL-M-38510	**Output** (Current Continuous)	.60	
		Output Current (Surge)	60	
		Input Voltage (Signal)	75	
		Supply Voltage (Surge)	80	
		Supply Voltage	Do not exceed Mfg. nominal rating	
Nonhermetically sealed voltage regulators	MIL-M-38510	Power	See derating requirements	See derating requirements
		Output Current (Continuous)	65	
		Output Current(Surge)	60	
		Input Voltage (Signal)	75	
		Supply Voltage (Surge)	80	
		Supply Voltage	Do not exceed mfg. nominal rating	
Digital Hermetically sealed micro-circuits	MIL-M-38510	Supply Voltage	Do not exceed mfg. nominal rating.	100
		Toggle Frequency	70	

		Set Up and Hold Time	200 minimum	
		Fanout	80	
Nonhermetically sealed microcircuits	MIL-M-38510	Supply Voltage	Do not exceed mfg. nominal rating.	75
		Toggle Frequency	70	
		Set Up and Hold Time	200 minimum	
		Fanout	80	

Table I-V. Derating Requirements for Connectors
(With an Ideal Heat Sink)

					Electrical	
PART TYPE	**MIL-SPEC**	**Insert Material Type**	**Contact Size**	**Para meter**	**Max. % of Rated Electrical Stress**	**Max Derated Temperature(°C)**
Connectors, General	All those listed in MIL-STD-1353	A	All those applicable	Pin Current Voltage	60 25 of the dielectric withstanding voltage	230
		B		Pin Current Voltage	60 25 of the dielectric withstanding voltage	170
		C		Pin Current Voltage	60 25 of the dielectric withstanding voltage	90
		D		Pin Current Voltage	60 25 of the dielectric withstanding voltage	90
Printed Circuit Board Connectors (PCBs)	All those listed in MIL-STD-1353	B	All those applicable	Pin Current Voltage	60 25 of the dielectric withstanding voltage	180

Table I-VI. Derating Requirements for Connectors
(With an Ideal Heat Sink)

				Electrical		
Part Type	**MIL-STD**	**Material Type**	**Contact Size**	**Parameter**	**Max. % of Rated Electrical Stress**	**Max Derated Temperature (°C)**
Connectors General	All those listed in MIL-STD -1353	A	22 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	200
		B	22.GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	140
		C	22 GA	Pin Current Voltage	60 25 of the dielectic withstanding voltage	60
		D	22 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	60
		A	20 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	190
		B	20 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	130
		C	20 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	50
		D	20 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	50
				Voltage		25 of the dielectric
Connectors General	All those listed in MIL-STD -1353	A	16 GA	Pin Current Voltage	60 25 of the dielectirc withstanding voltage	190

		B	16 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	130
		C	16 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	50
		D	16 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	50
		A	12 GA	Pin Current Voltage	6025 of the dielectric withstanding voltage	195
		B	12 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	135
		C	12 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	55
		D	12 GA	Pin Current Voltage	6025 of the dielectirc withstanding voltage	55
Printed Circuit Connectors (PCBs)	All those listed in MIL STD-1353	B	26 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	165
		B	22 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	170e
		B	20 GA	Pin Current Voltage	6025 of the dielectric withstanding voltage	175

Table I-VII. Parts Derating Requirements for Relays

Electrical

MIL-STD	**MIL-STD**	**Parameter**	**Max. % of Rated Electrical Stress**	**Maximum Derated Ambient Temp. (°C)**
Relays	All those listed in	Contact Current	60- Capacitive load 60- Resistive load	Limit to 65ºC when rated at 85ºC or

	MIL-STD-1346	(Continuous)	40- Inductive load 20- Motor 10- Filament (Lamp)	100ºC when rated at 125ºC
		Contact Current (Surge)		80
		Vibration	75 (including “Q” of mounting)	
Switches	All those listed in MIL-STD-1346	Contact Current (Continuous)	60- Capacitive load 60- Resistive load 40- Inductive load 20- Motor 10- Filament (Lamp)	Limit to 20ºC -- 25ºC below the specified maximum rated temperature
		Contact Current (Surge)	80	
		Vibration	75 (including “Q” of mounting)	

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Appendix G -- Applicable Documents

The following documents of the issue in effect on the date of invitation for bids or request for proposal form a part of this document. The cited documents shall not take precedance over this document, but should be consulted for supplemental information pertaining to the application of electronic and electromechanical parts.

Specifications

Military

MIL-R-19	Resistor, Variable, Wirewound (Low-Operating Temperature), General Specification for
MIL-C-20	Capacitor, Fixed Ceramic Dielectric (Temperature Compensating), Established and Non-Established Reliability, General Specification for
MIL-R-22	Resistor, Variable (Wiresound Power Type), (Unenclosed), General Specification for
MIL-R-26	Resistor, Fixed, Wirewound (Power Type), General Specification for
MIL-T-27	Transformer and Inductor (Audio, Power and High-Power Pulse), General Specification for
MIL-C-81	Capacitor, Variable, Ceramic Dielectric, General Specification for
MIL-R-94	Resistor, Variable, Composition, General Specification for
MIL-C-3098	Crystal Units, Quartz, General Specification for
MIL-C-3432	Cable and Wire, Electrical (Power and Control; Flexible and Extra flexible, 300 and 600 Volts)
MIL-S-3786	Switch, Rotary (Circuit Selector, Low-Current Capacity), General Specification for
MIL-S-3950	Switch, Toggle, Environmentally Sealed, General Specification for
MIL-C-5015	Connector, Electrical, Circular Threaded, AN Type, General Specification for
MIL-B-5423	Boot, Dust and Water Seal, General Specification for
MIL-R-5757	Relay, Electrical (for Electronic and Communication Type Equipment),

	General Specification for
MIL-R-6106	Relay, Electromagnetic (including Established Reliability (AN) Types), General Specification for
MIL-S-6807	Switch, Rotary, Selector, Power, General Specification for
MIL-G-7703	Guard, Switch, General Specification for
MIL-S-8805	Switches and Switch Assemblies, Sensitive and Push (Snap Action), General Specification for
MIL-S-8805	Switches and Switch Assemblies, Sensitive and Push (Snap Action), General Specification for
MIL-S-8834	Switch, Toggle, Positive Break, General Specification for
MIL-S-9395	Switches, Pressure (Absolute Gage and Differential), General Specification for
MIL-H-10056	Holder (Enclosures), Crystal, General Specification for
MIL-R-12934	Resistor, Variable, Wirewound (Piston Type, Tubular Trimmer), General Specification for
MIL-C-14409	Capacitor, Variable (Piston Type, Tubular Trimmer), General Specification for
MIL-S-15291	Switch, Rotary, Snap Action, General Specification for
MIL-15305	Goil, Fixed and Variable, Radio Frequency, General Specification for
MIL-F-15733	Filter, Radio Interference, General Specification for
MIL-F-18327	Filter, High Pass, Low Pass, Band Pass, Band Suppression and Dual Functioning, General Specification for
MIL-R-18546	Resistor, Fixed, Wirewound (Power Type, Chassis Mounted), General Specification for
MIL-S-19500	Semiconductor Device, General Specification for
MIL-C-19978	Capacitor, Fixed, Plastic (or Paper Plastic), Dielectric (Hermetically Sealed in Metal, Ceramic or Glass Cases), Established Reliability, General Specification for

MIL-T-21038	Transformer, Pulse, Low Power, General Specification for
MIL-C-21097	Connector, Electrical, Printed Wiring Board, General Purpose, General Specification for
MIL-S-22710	Switch, Rotary (Printed Circuit), (Thumbwheel, Inline and Push Button), General Specification for
MIL-S-22885	Switch, Push Button, Illuminated, General Specification for
MIL-C-22992	Connector, Plugs and Receptacles, Electrical, Water-Proof, Quick Disconnect, Heavy Duty Type, General Specification for
MIL-C-23183	Capacitor, Fixed or Variable, Vacuum Dielectric, General Specification for
MIL-C-23269	Capacitors, Fixed, Glass Dielectric, Established Reliability, General Specification for
MIL-R-23285	Resistor, Variable, Non-wirewound, General Specification for
MIL-S-24236	Switch, Thermostatic (Metallic and Bimetallic), General Specification for
MIL-S-24308	Connector, Electric, Rectangular, Miniature, Polarized Shell, Rack and Panel, General Specification for
MIL-S-24317	Switch, Multistation, Push Button (Illuminated and Nonilluminated), General Specification for
MIL-C-28731	Connector, Electrical, Rectangular, Removable Contact, Formed Blade, Fork Type (For Rack and Panel and Other Applications), General Specification for
MIL-C-28748	Connector, Electrical, Rectangular, Rack and Panel, Solder Type and Crimp Type Contacts, General Specification for
MIL-R-28750	Relay, Solid State, General Specification for
MIL-R-28776	Relays, Hybrid, Established Reliability, General Specification for
MIL-M-28788	Switches, Air and Liquid Flow Sensing, General Specification for
MIL-C-28804	Connector, Electric, Rectangular, High Density, Polarized Center, Jackscrew, General Specification for
MIL-S-28827	Switch, Thermostatic (Volatile Liquid), hermetically Sealed, General Specification for
MIL-M-38510	Microcircuits, General Specification for

MIL-C-38999	Connector, Electrical, Circular, Miniature, High Density, Quick Disconnect, Bayonet, Threaded and Breech Coupling, Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for
MIL-C-39001	Capacitor, Fixed, Mica Dielectric, Established Reliability, General Specification for
MIL-R-39002	Resistor, Variable, Wirewound, Semiprecision, General Specification for
MIL-C-39003	Capacitor, Fixed, Electrolytic (Solid Electrolyte), Tantalum, Established Reliability, General Specification for
MIL-R-39005	Resistor, Fixed, Wirewound (Accurate), Established Reliability, General Specification for
MIL-C-39006	Capacitor, Fixed, Electrolytic (Non-Solid Electrolyte) Tantalum, Established Reliability, General Specification for
MIL-C-39007	Resistor, Fixed, Wirewound (Power Type), Established Reliability, General Specification for
MIL-R-39009	Resistor, Fixed, Wirewound (Power Type, Chassis Mounted), Established Reliability, General Specification for
MIL-C-39010	Coil, Fixed, Radio Frequency, Molded, Established Reliability, General Specification for
MIL-C-39012	Connector, Coaxial, Radio Frequency, General Specification for
MIL-C-39014	Capacitor, Fixed, Ceramic Dielectric (General Purpose), Established Reliability, General Specification for
MIL-R-39015	Resistor, Variable, Wirewound (Lead Screw-Actuated), Established Reliability, General Specification for
MIL-R-39016	Relay, Electromagnetic, Established Reliability, General Specification for
MIL-R-39017	Resistor, Fixed, Film (Insulated), Established Reliability, General Specification for
MIL-C-39018	Capacitor, Fixed, Electrolytic (Aluminum Oxide), Established Reliability and Non-Established Reliability, General Specification for
MIL-C-39022	Capacitor, Fixed, Metallized, Paper or Paper-Plastic, Film or Plastic Film Dielectric, DC and AC (Hermetically Sealed in Metal Cases), Established Reliability, General Specification for
MIL-R-39023	Resistor, Variable, Non-wirewound, Precision, General Specification for

MIL-C-39024	Connector, Electrical, Jacks, Tip (Test Point, Panel or Printed Wiring Type), General Specification for
MIL-C-39029	Contact, Electrical Connector, General Specification for
MIL-R-39035	Resistor, Variable, Non-wirewound (Adjustment Type), Established Reliability, General Specification for
MIL-C-55181	Connector, Plug and Receptacle, Intermediate (Electrical), (Water-Proo Reliability, General Specification for f),
MIL-R-55182	Resistor, Fixed, Film, Established Reliability, General Specification for
MIL-C-55302	Connector, Printed Circuit Subassembly and Accessories, General Specification for
MIL-R-55342	Resistor, Fixed, Film, Chip, Established Reliability, General Specification for
MIL-C-55365	Capacitor, Chip, Fixed, Tantalum, Established Reliability, General Specification for
MIL-S-55433	Switch, Capsules, Dry Reed Type, General Specification for
MIL-C-55661	Capacitor, Electrical, Rectangular, Crimp Contacts, General Specification for
MIL-C-81659	Connector, Electrical, Rectangular, Crimp Contacts, General Specification for
MIL-C-83421	Capacitors, Fixed, Supermetallized, Plastic Film Dielectric, (DC, AC or DC and AC), Hermetically Sealed in Metal CAses, Established Reliability
MIL-C-83446	Coils, Radio Frequency, Fixed or Variable
MIL-R-83401	Resistor Networks, Fixed, Film, General Specification for
MIL-C-83502	Socket, Plug-In Electronic Components, Round Style, General Specification for
MIL-C-83505	Socket (Lead, Electronic Components), General Specification for
MIL-R-83726	Relay, Time Delay, Hybrid and Solid State, General Specification for
MIL-R-83733	Connector, Electrical, Miniature, Rectangular Type, Rack to Pa Environmental Resisting, 200ºC Total Continuous Operating Temperature, General Specification for,

MIL-S-83734	Socket, Plug-in, Electronic Components, General Specification for

Federal

WC-596	Connector, Plug, Receptacle and Cable Outlet, Electrical Power, General Specification for

Standards

Military

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-198	Capacitors, Selection and Use of
MIL-STD-199	Resistors, Selection and Use of
MIL-STD-202	Test Methods for Electronic and Electrical Components Parts
MIL-STD-242	Electronic Equipment Parts, Selected Standards

(Navy)

MIL-STD-255	Electric Voltages Alternating and Direct Current
MIL-STD-454	Standard General Requirements of Electronic Equipment
MIL-STD-683	Crystal Units (Quartz) and Crystal Holders (Enclosures), Selection of
MIL-STD-690	Failure Rate Sampling Plans and Procedures
MIL-STD-701	List of Standard Semiconductor Devices
MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-721	Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors and Safety
MIL-STD-750	Test Methods for Semiconductor Devices
MIL-STD-785	Reliability Program for Systems and Equipment Development and Production

MIL-STD-790	Reliability Assurance Program for Electronic Parts Specifications
MIL-STD-883	Test Methods and Procedures for Microelectronics
MIL-STD-965	Parts Control Program
MIL-STD-1132	Switches and Associated Hardware, Selection and Use of
MIL-STD-1286	Transformers, Inductors, and Coils, Selection and Use of
MIL-STD-1346	Relays, Selection and Application
MIL-STD-1353	Electrical Connectors, Plug-In Sockets and Associated Hardware, Selection and Use of
MIL-STD-1378	Requirements for Employing Standard Electronic Modules
MIL-STD-1389	Design Requirements for Standard Hardware Program Electronic Modules
MIL-STD-1395	Filters and Networks, Selection and Use of
MIL-STD-1399	Interface Standard for Shipboard Systems
MIL-STD-1531	Insert Arrangements for MIL-C-83733 Rack to Panel Connectors, Shell Size B
MIL-STD-1532	Insert Arrangement for MIL-C-83733 Rack to Panel Connectors, Shell Size B
MIL-STD-1554	Insert Arrangements for MIL-C-38723 Series 3 and MIL-C-26500 Environment Resisting, circular, Electrical Connectors
MIL-STD-1560	Insert Arrangement for MIL-C-38999 and MIL-C-27599 Electrical, Circular Connectors
MIL-STD-1562	Lists of Standard Microcircuits
MIL-STD-1632	Insert Arrangements for MIL-C-28804, High Density, Rectangular, Electrical Connectors
MIL-STD-1634	Module Descriptions for the Standard Electronic Modules Program
MIL-STD-1651	Insert Arrangements for MIL-C-5015, MIL-C-22992 (Classes C, J and R) and MIL-C-83823 (Series II) Electrical Connectors
MIL-STD-1665	Test Equipment for the Standard Electronic Modules program
MIL-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically

Initiated Explosive Devices)

Handbooks

Military

MIL-HDBK-217	Reliability Prediction of Electronic Equipment
MIL-HDBK-239	Navy Standard Hardware Program Application Handbook
MIL-HDBK-246	Program Managers Guide for the Standard Electronic Modules Program
MIL-HDBK-251	Reliability/Design Thermal Applications
MIL-HDBK-978	(NASA) NASA Parts Application Handbook
DOD-HDBK-263	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)

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Section 900 -- Filters

900 Filters

900.1 General Information

Standard filters should be selected from MIL-STD-1395. The variety of filter and network types used in any particular equipment should be the minimum necessary to obtain satisfactory performance. Where more than one type filter or network can be used in a given application (i.e., L-C, R-C, L-R, electro-mechanical, piezo-electric crystal, etc.) consideration should be given to cost and availability (use of strategic materials, multiple sources, etc.). The filters and networks identified herein meet all the criteria for standard types as identified in MIL-STD-1395.

900.2 Application Considerations

900.2.1 Item Identification

Part numbers used to identify the filters and networks listed herein are as specified in the individual filter or network specification. Type designations can be constructed as indicated in examples given in applicable sections of this manual.

900.2.2 Insulation Resistance

Careful consideration shall be given to the insulation resistance of filters. The value of insulation resistance varies with temperature, and it is necessary to apply a correction factor to measurements made at temperatures other than 25ºC. Table 900-I gives correction factors for measurements made at temperatures between 20ºC and 35ºC. The required value of insulation resistance shall be multiplied by the correction factor to determine the new value required at the new temperature.

Table 900-I -- Correction Factors

Degrees Centigrade	Correction Factor	Degrees Centigrade	Correction Factor
20	1.42	28	0.82
21	1.33	29	0.76
22	1.24	30	0.71
23	1.16	31	0.67
24	1.08	32	0.63

25	1.00	33	0.59
26	0.94	34	0.55
27	0.87	35	0.51

900.2.3 Insertion-Loss and Discrimination

The design engineer should give consideration to insertion-loss and discrimination characteristics of the filter for its application. This will provide transmission of desirable frequencies through the filter at acceptable levels, while providing the necessary attenuation of undesirable frequencies.

900.3 Derating Requirements

Filters shall be derated according to Table 900-II.

Table 900-II -- Derating Factors

Derating Parameter	Max % of the Rated Value
Current	50
Working Voltage	50
Operating Temperature	20ºC less than the specified maximum

901 Filters, Radio Interference

901.1 MIL-F-15733, Filters, Radio Interference

901.1.1 Application Considerations

901.1.1.1 Use

These filters are current carrying filters, ac and dc, and are used primarily for the reduction of broadband radio interference. They are also applicable to shielded room and power factor applications.

901.1.1.2 Rated Frequency

These filters are applicable for use in equipment requiring frequency ratings up to 1,000 MHz.

901.1.1.3 Construction

These filters consist of discrete component parts (inductors and capacitors) arranged in the popular circuit configurations such as “Pi”, “L”, and “T”. They are enclosed in hermetically sealed metallic enclosures, with all exposed metallic surfaces protected against corrosion by plating, lead alloy coating, or other means.

901.1.1.4 Voltage Rating

The filters covered by this section are of two types: those rated for direct current use, and those rated for both alternating current and direct current use. The direct current types are rated at 100 volts dc, and the ac-dc types are rated at 125 volts ac and 400 volts dc.

901.1.1.5 Current Rating

These filters are available in seven current ratings from 1 ampere to 30 amperes.

902 Filters, Band Pass

902.1 MIL-F-18327, Filters, High Pass, Low Pass, Band Pass, Band Suppression and Dual Functioning

902.1.1 Application Considerations

902.1.1.1 Use

These filters are designed for use in applications with a wide range of source and load impedances ranging from a few ohms to several megohms.

902.1.1.2 Terminals

These filters are equipped with solder lug and pin type terminals. They are provided with external mounting studs, lock nut or flat washer, lock washer, and nut.

902.1.1.3 Construction

The filters covered by this section are composed of combinations of inductors, capacitors, resistors, piezo-electric crystals, electro-mechanical and other electronic components arranged in electrical configurations which provide insertion-loss and discrimination characteristics required in a particular filter.

903 Quality Level

Only ER level “P” or higher shall be used.

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Section 1000 -- Magnetic Devices

1000 Magnetic Devices

1000.1General Information

Standard transformers, inductors and coils are specified in MIL-STD-1286. The selection of a transformer, inductor, or coil should consider such factors as circuit function, construction, circuit application, operating temperature, altitude, type of mounting, environmental conditions, size, weight, life expectancy, and reliability. These factors are described herein. After the preliminary selection of a transformer, inductor or coil, the appropriate military specifications and MS drawings should be examined to verify that the item parameters important to the new application are controlled to the degree necessary.

1000.2 Application Considerations

Application considerations are as follows:

1000.2.1 Power Transformers and Inductors

1000.2.1.1 Frequency

Power transformers and inductors are designed to operate efficiently over a fixed frequency range. Operation outside this range, will result in overheating. Lower frequencies will tend to saturate the core and higher frequencies will increase core losses.

1000.2.1.2 Capacitive Loads

Transformers that drive rectifier circuits with capacitive input filters require special consideration. Capacitive input filters cause the current through the transformer to be very non-linerar, since the current used to keep the input capacitor charged is much greater than the average current delivered to the load. (Current is delivered to the input filter only when the rectifier output voltage exceeds the stored voltage in the capacitor.) The result is that average current through the transformer is the same as average current delivered to the load. However, initially the current is delivered as a series of spikes of much higher amplitude than the steady state current. Since transformer heating is a function of current squared, transformer internal power dissipation will be greater with a capacitive input filter than with an inductive input filter.

1000.2.1.3 Saturation

Power inductors used as filters usually carry a large direct current component. If this component exceeds the value specified, the inductance can be reduced because of core saturation.

1000.2.2 Audio Transformers

1000.2.2.1 Saturation

Audio transformers are not normally designed to accommodate any direct current. Small amounts of direct current can cause core saturation with significant performance degradation, especially at low frequencies.

1000.2.2.2 Resistance Change with Temperature

The temperature coefficient of resistance for copper windings is approximately 0.4%/ºC. This change in resistance can be significant in some applications. Most military equipment is required to operate over a large temperature range. An analysis should be performed to ensure that such resistance variations are compatible with design requirements.

1000.2.2.3 Shielding

Electrostatic or electromagnetic shielding may be required in low level circuits to avoid noise or hum pickup.

1000.3 Derating Requirements

Transformers, inductors, coils, and RF coils shall be derated according to the parameters shown in Table 1000-I. It should be noted that in the event of selection and use of custom designed transformers or inductors, there may be no specific temperature rating assigned. In these instances a maximum temperature rise above ambient not exceed 25ºC should be used, with 40ºC for hot spot temperature; and derate accordingly. To avoid double derating, devices designed for current density of 2mA per circular mil should not be derated for continuous and surge current.

Table 1000-I -- Derating Requirements for Transformers, Inductors, Coils, and RF Coils

Part Type:	Derating Parameters	Max. % of Rated Value
Transformers, Inductors and Coils		
	Current (Continuous) Current (Surge) Voltage(Continuous)	2mA per cir. mil. 70 80 70 of insulation breakdown for devices above 1,500 volts working voltage; 50 of insulation breakdown for devices up to 1,500 volts working voltage; or mfg. recommended operating voltage whichever is less.

	Voltage (Surge) 80	80
	Hot Spot Temperature (Operating)	Limit 65 of specified maximum
RF Coils:	Current (DC)	50
	Hot Spot Temperature (Operating)	Limit to 65 of specified maximum

1001 Transformers/Inductors

1001.1 MIL-T-27, Transformers and Inductors, Power, Audio Frequency, High Power Pulse

1001.1.1 Application Considerations

The MIL-T-27 transformers and inductors shall be applied according to Table 1000-II.

Table 1000-II -- Application of MIL-T-27, Transformers and Inductors

Application	**Grade Required***	**Temperature Class**
Shipboard, transportable and ground-mobile	4 or 5	R, S, V or T
Ground-fixed	4 or 5	Q, R, S or V
Aircraft and missile	4 or 5	R, S, T or U

* Grade 6 transformers and inductors may be used in hermetically sealed or encapsulated assemblies only

1001.2 MIL-T-21038, Transformers, Pulse, Low Power

1001.2.1 Application Considerations

MIL-T-21038 transformers shall be applied according to Table 1000-III.

Table 1000-III -- Application of MIL-T-21038, Transformers

Application	**Grade**	**Temperature Class**	**Life Expectancy**
Shipboard, transportable and	4 or 5	R, S, T or U	X

ground-mobile			
Ground-fixed	4 or 5	Q, R, S or T	X
Aircraft and missile	4, 5, 6, or 7	R, S, U or V	X

1002 Coils, Radio Frequency

1002.1 MIL-C-15305, Coils, Radio Frequency

MIL-C-15305 covers radio frequency coils, fixed and variable, for use as simple inductive elements in radio frequency circuits.

1002.2 MIL-C-39010, Coils, Fixed, Radio Frequency, Established Reliability

MIL-C-39010 covers radio frequency, molded coils which have a specified reliability for use in equipment where reliability, long life, and continuity of operation are necessary.

1002.2.1 Quality Levels

Only ER level “P” or higher shall be used.

1002.3 MIL-C-83446, Coils, Radio Frequency, Fixed or Variable

MIL-C-83446 covers fixed or variable chip radio frequency coils intended for incorporation into hybrid microelectronic circuits.

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Appendix A -- Thermal Analysis

A.1 General

The power dissipated in a component causes a temperature rise which can affect performance and reliability. Such temperature changes must be taken into account when designing a circuit, selecting parts, and deriving a physical circuit configuration. One method of doing this is to do a thermal analysis. This appendix provides an introduction to general procedure and sets guidelines on how thermal analysis should be done. MIL-HDBK-251 Reliability/Design Thermal Applications should be referred to for more detailed and extensive information.

As circuit operating temperature increases, physical changes take place within the component parts. These cause variations in part electrical parameters, which can degrade performance and increase the likelihood of failures.

Chronic high temperature may not always cause immediate catastrophic failure. However, there is always a slow, progressive deterioration of the part along with acceleration of any chemical reactions which eventually lead to failure. Dielectrics, metallization areas, transistor junctions, and many other materials degrade faster with increase in temperature. These effects are cumulative so that failure rates depend, to some extent, on the entire thermal history of the part. In addition, many part performance ratings decrease as ambient temperatures increase. A thermal profile analysis determines the air (to sink) temperature in the vicinity of the part. A thermal profile analysis is therefore mandatory to the stress analysis/derating process.

It should be emphasized that thermal design alone, including effective cooling of parts, is not necessarily a cure-all for high electrical stresses. While many parts are thermal sensitive, many others are voltage or current sensitive. Increased reliability requires both control of part temperatures and use of parts with electrical ratings adequate for the application.

This appendix presents general guidelines and requirements for thermal analysis. For more detailed and extensive information use MIL-HDBK-251.

A.2 Definitions

Emissivity -- The ratio of radiation intensity from a surface to the radiation intensity from a black body at the same temperature and wave length. As applied in this appendix, a measure of a surface’s ability to radiate heat.

Heat Concentration -- Heat dissipation per unit volume expressed in watts per cubic unit of measure (cubic inch, cubic foot, or other appropriate unit).

Heat Dissipation -- The difference between the electrical input and output of an electronic device, expressed in watts, except where mechanical work is being accomplished; e.g., motors.

Heat Flow Rate -- The power flowing along a thermal path expressed in watts. The symbol used for heat flow rate is (q).

Internal Temperature -- The temperature of a gas, liquid, or solid at a specified location within an enclosure.

Point Surface Temperature -- The average temperature at a specified location on a surface.

Thermal Conductance -- Thermal Conductance is the reciprocal of Thermal Resistance. The units are generally watts per ºC.

Thermal Resistance -- The resistance to heat flow generally in units of ºC per watt and identified as 0.

Thermal Environment -- The condition of (1) fluid type, temperature, pressure, and velocity; (2) surface temperatures, configurations, and emissivities; and (3) all conductive thermal paths surrounding an electronic device.

View Factor -- A measure of the view angle of the absorbing material with respect to the emitting material in heat radiation transfer.

A.3 Basic Thermal Profile Analysis Guidelines

This section presents the basic guidelines for developing the thermal resistance values for conduction, convection and radiation. It then presents methods for combining these in an equivalent thermal network displaying the thermal profile.

A.3.1 Procedure

a. Determine the outside temperature from the equipment operating specifications. Find out what types of cooling techniques will be available and what their constraints are (e.g., pressures, air flow rates, etc.).

b. Find the power requirements of individual modules or boards. From this, derive how much heat must be dissipated by each module or board and produce a general heat flow model. This model usually takes the form of an electrical circuit analogy, with electrical resistance corresponding to thermal resistance, potential difference to temperature gradients, and current to heat flow. The model should begin with the outside, coolant, or heat sink temperature. At first, it should extend only to the board level. Later, it should continue down to the part level. It does not need to extend to each individual part however. Groups of similar parts in the same general area of the circuit assembly should be grouped together to simplify calculations. It should only extend to individual parts if the parts are large heat producers or have heat sinks. It should also include the heat flow from one circuit to another.

c. From the circuit analysis, find the power dissipated by each device. In step b in which parts were grouped together, add the power dissipation of the parts in each group. Enter these values into the thermal network developed in step b. Knowing the outside air temperature and thermal resistivities, work backwards to find ambient temperatures. Several iterations may be needed because thermal resistivity is dependent to some extent on temperature. This step should be done during the breadboard phase of the design.

d. Measure ambient temperatures to confirm the calculated values in step c. Resolve any difference by refining the thermal model. This step should be done just after circuit fabrication and assembly.

Note: Steps c and d are very similar. Basically, they use two different methods for arriving at the same result. Step c uses engineering analysis to determine temperatures, and step d uses actual measurements. The degree to which each is used is dependant on where the thermal analysis takes place in the design process. Ideally, the two steps should be done at two different points in the design process. Step c should be done at the breadboard level to design the basic cooling system, and step d should be done at the production circuit assembly level to confirm the breadboard level results.

e. Use part specifications to find maximum part temperature ratings. Derate the maximum ratings in accordance with this manual. Use the ambient temperatures found in step d to determine whether parts may be exceeding their maximum ratings.

f. The results of the thermal analysis will indicate which parts exceed absolute maximum and derated maximum limits. For each of these parts corrective action may consist of:

(1) use of a higher rated part,
(2) refinement of the power dissipation capability of the part, or
(3) change of electrical design, or
(4) change of thermal design.

g. After corrective actions have been taken, steps e and f must be repeated to assure no additional problems have been created.

A.4 Thermal Ratings of Parts

For today’s densely packaged equipment, the local air temperature (ambient) surrounding a part is related to both the part’s own power dissipation and of nearby parts and structures. Even though the part’s own power dissipation may not cause overheating, nearby parts may. A typical example is a silicon microcircuit mounted next to a wirewound power resistor. The microcircuit may not dissipate much power, but the resistor can have a hot spot temperature rise of 230ºC when operating at full power. Most silicon microcircuits would fail if mounted close to this hot spot.

The maximum temperature a semiconductor can withstand can be given as either junction, case, or ambient temperature. All three are related to each other through thermal resistance paths.

Thermal resistance is the ratio of temperature change to power dissipation under steady state conditions. It is mathematically defined as:

$$\theta = \Delta T/PD$$

where:

θ = Thermal Resistance
ΔT = Change in Temperature
PD = Power Dissipation

The units of thermal resistance are ºC/watt.

Thermal resistance for active solid-state devices such as transistors may be specified by three different constants:

θ_{JC} = Thermal Resistance, Junction to Case;
θ_{CA} = Thermal Resistance, Case to Ambient; or
θ_{JA} = Thermal Resistance, Junction to Ambient.

All three are related to each other by the equation:

$$\theta_{JA} = \theta_{JC} + \theta_{CA}$$

Junction, case, and ambient temperatures are related to each other by:

$$T_J = T_C + PD\theta_{JC}$$
$$T_C = T_A + PD\theta_{CA}$$

However, this is only under steady state DC operation. Under pulsed operation, the situation changes. For high frequency pulses, temperature usually increases faster. As frequency decreases, so does temperature. This is because the part cools while it is off. Therefore, the nature of the duty cycle makes a difference. A high duty cycle may increase temperature, and a low duty cycle decrease it. For many devices which are repetitively switched on and off (e.g., thyristors), maximum temperature versus frequency and duty cycle information is provided in the component specifications.

A.5 Thermal Evaluation and Design for Heat Transfer

The fundamental principles used in a thermal profile analysis are presented in this section. Ideally, small temperature gradients and consequently low operating temperatures indicate that effective heat transfer techniques have been used. Two basic assumptions used in this analysis are: (1) positive heat flow is the heat flow from a high temperature region to a low temperature region, and (2) heat emitted by a high temperature region is equal to the heat absorbed by a low temperature region.

There are three basic methods of heat transfer: conduction, convection, radiation. Heat can also be transferred by mass transfer (i.e., evaporation and condensation), but this will not be discussed.

A.5.1 Heat Conduction

Heat conduction is caused by molecular oscillations in solid materials and elastic impact of molecules in liquids and gases. Heat flow in liquids and solids is analogous to ohms law for current flow in a circuit. The resistance to heat flow is analogous to the resistance to current flow in a circuit, and temperature difference is analogous to potential difference.

For heat flowing through a region of constant cross sectional area, the equation for heat conduction is:

$$\theta_{cond} = \frac{\Delta T}{q}$$

Where:

θ_{cond} = thermal resistance to heat conducted through and along the region
ΔT = temperature gradient across the conductive path (ºC)
q = heat flow rate through and along the conductive path (watts)

The units of θ_{cond} are therefore ºC/watt.

A second general relation for thermal resistance can be used, which is based on analogy to electric circuit resistance:

$$R_{\text{Electric Circuit}} = \frac{1L}{\sigma A}$$

where:

σ = electrical conductivity
L = circuit path
A = circuit wiring cross-sectional area

Accordingly, for heat conduction:

$$\theta_{cond} = \frac{1L}{KA}$$

where:

K = thermal conductivity (watt/ºC-in)
L = conduction path length (in^2)
A = conduction path cross-sectional area (in^2)

So that the equations for heat conduction are:

θ_{cond} = T/q

$\theta_{cond} = L/KA$

A.5.2 Heat Convection

Heat convection is the process where heat is transferred from a solid surface to a moving fluid or gas. The circulation of the fluid or gas removes heat from a warm area and transfers it to a cooler area.

The equation for heat convection is as follows:

$\theta_{conv} = \Delta T/q$

using a basic relation for convective heat transfer:

$q = h_c A_s \ \Delta T_s$

Where:

q = Heat Flow Rate (watt)

A_s = Heated Surface Area (in^2)

ΔT_s = Temperature gradient from the surface to the ambient in the near vicinity of the surface (ºC)

h_c = The convective heat transfer coefficient, a complex function of the fluid flow, thermal properties of the ambient, the geometry of the system (i.e., size, shape, surface texture, etc.), as well as a function of temperature itself. However, for most electronic components in air,h_c may be approximated by the value 0.003 watts/in ^{2o}C (See table A.2 for other values.)

Then we can write:

$$\theta_{conv} = \frac{\Delta T}{q} = \frac{\Delta T}{h_c A_s \ \Delta t_s} = \frac{1}{h_c A_s}$$

Convection is more complicated than conduction because the convective heat transfer coefficient h_c is a nonlinear function of ΔT. It also varies much more with temperature than thermal resistivity. However, approximate values of the temperatures are usually known. More exact values, within ±5 percent, can be calculated using a successive approximation method of two or three steps. This is good enough for most electronic equipment cooling designs.

Convection heat transfer coefficients are usually relatively small so that the corresponding θ_{conv} is high compared to θ_{cond}. In situations in which conduction and convection are serially occurring, convection is usually the dominant heat transfer limiting factor. Two types of convective heat transfer are of interest. When the ambient fluid is moved by external means such as fans or pumps, the process is termed forced convection; fluid motion due to density decreases of the heated fluid with resultant changes in buoyancy is termed free convection.

There are separate convective coefficients for vertical and horizontal, and top and bottom surfaces. A further expansion of the convection equation for thermal resistance could be performed using the individual surfaces.

Table A.1 -- Thermal Conductivity "K" of Typical Materials

Material	**Thermal Conductivity W/in-°C**	**Material**	**Thermal Conductivity W/in-°C**
Metals		***Insulators***	
Aluminum	5.5	Still air	0.0007
Beryllium	4.5	Alumina (99.5%)	0.70
Beryllium copper	2.70	Alumina (85%)	0.30
Brass (70% copper-30% zinc	3.10	Beryllia (99.5%)	5.0
Copper	10.0	Beryllia (97%)	4.0
Gold	7.40	Beryllia (95%)	3.0
Iron	1.70	Boron nitride (hot pressed)	1.0
Kovar	0.42		
Lead	0.87	Diamond	16.0
Magnesium	4.0	Epoxy "Thermally conducting"	0.02
Molybdenum	3.30		
Monel	0.50	Epoxy	.005
Nickel	2.30	Glass	0.02
Silver	10.6	"Heat Sink Compound" metal oxide loaded epoxy)	0.01

Stainless steel 321	0.37		
Stainless steel 410	0.61	Mica	0.018
Steel, low carbon	1.70	Mylar	0.005
Tin	1.60	Phenolic	0.005
Titanium	0.40	Silicone Grease	0.005
Tungsten	5.0	Silicone Rubber	0.005
Zinc	2.60	Teflon	0.005
Semiconductors			
Gallium arsenide	1.5		
Silicon (pure)	3.7		
Silicon (doped to resistivity of .0025 ohm-cm)	2.5		

Table A.2 -- Convection Heat Transfer Coefficient

Cooling Technique	**Heat Transfer Coefficient h_c W/in^2-^{o}C**
Free Convection	.0018 to .0037
High Altitudes 21,336m (70 kft)	Closer to .0018
Sea Level	Closer to .0037
Air Impingement	.011 to .018
Forced Convection	
Air over plain fins	.022 to .110
Air over interrupted fins	3 to 5 times higher than plain fins
Liquid Cooling	
Dielectric liquid	.368 to 1.465
Water	1.806 to 36.77

A.5.3 Heat Radiation

Radiation is the transfer of heat through electromagnetic energy. Radiation travels from a warmer body (emitter) to a cooler body (heat sink), with the assumption of relatively little absorption from the air. When reaching a cooler body the energy is either absorbed, reflected, or is transmitted through. The transmitted energy is usually insignificant.

The amount of energy absorbed or reflected depends on the surface characteristics of the body, such as color and finish. Perfectly black bodies are defined as those which absorb all the radiation, while perfectly shiny bodies reflect all radiation. The radiation characteristics of a surface are defined by a dimensionless quantity known as emissivity. A perfect absorber and emitter has an emissivity of one, and a perfect reflector has an emissivity of zero. Table A.3 lists the emissivity of several common materials.

The rate of heat transfer by radiation is low when the difference in temperature between the emitting and absorbing bodies is small, or the temperature of the bodies are close to room temperature. The thermal resistance due to radiation decreases rapidly as the temperature difference between the emitting and absorbing bodies increases. This is because the heat flow rate, q_{rad}, is:

$$q_{rad} = \sigma_s e_r F_{es} A (Te^4 - Ts^4) \text{ watts}$$

where:

σ_s = 36.8 x10^{-12} w/in^2 _K^4 (Stefan-Boltzmann constant)
e_r = a composite emissivity and = e_1 x e_2; where
e_1 = emissivity of the radiating surface
e_2 = emissivity of the sink surface
F_{es} = A view factor
A = radiating surface area (in^2)

For two non-black bodies, the relation for net rate of exchange of radiant heat is:

$$q_{rad} = \sigma_s F_e F_a A (T_1 - T_2)$$

where:

F_e = an emissivity factor
F_a = a physical configuration factor based on the geometry of the situation

For the commonly occurring instance of essentially parallel planes which are large compared to their distance apart, the emissivity factor F_e is a composite of the emissivities of the surface and is of the form:

$$F_e = \frac{1}{\frac{1}{E_1} + \frac{1}{E_2} - 1} = \frac{E_1 E_2}{E_1 + E_2 - E_1 E_2}$$

The configuration factor F_a is sometimes known as the view factor (see table A.4 and section A.2 for representative values and clarifying definition).

Substituting for q_{rad}, then:

$$O_{rad} = \frac{Te - Ts}{F_e\, F_a\, \sigma_s\, A\, (T_e -- T_s)}\ {}^{\circ}\mathrm{K/watt}$$

The above expression is in ºK/W, where Kelvin is the absolute unit of temperature. Degrees centigrade can be converted to degrees Kelvin by:

K = C + 273

Since the Kelvin scale and centigrade scale are identical units except for the additive constant of 273, once the thermal resistance for radiation is determined in ºK/watt, the same resistance can be used for ºC/watt. In other words, a 1ºK rise is equal to a 1ºC rise.

Table A.3 -- Emissivity Factor [Surfaces at 4ºC (40_F)]

Surface	**Emissivity (E)**
Silver	0.02
Aluminum (buffed)	0.03
Aluminum (dull)	0.03
Gold (plated)	0.03
Gold (vacuum deposited)	0.03
Aluminum foil (shiny)	0.04
Aluminum (polished)	0.05
Stainless steel (polished)	0.05
Chrome	0.08
Tantalum	0.08
Beryllium (milled)	0.11
Beryllium (polished)	0.09
Rene 41	0.11

Nickel	0.18
Titanium	0.20
Aluminum (sandblasted)	0.40
White silicone paint (gloss)	0.75
Black silicone paint (flat)	0.81
Black vinyl phenolic (dull)	0.84
Lamp black	0.95
Magnesia	0.95
Grey silicone paint	0.96

Table A.4 -- View Factors for Various Configurations

Configuration	**View Factor**
Infinite parallel planes	1.0
Body completely enclosed by another body; internal body cannot see any part of itself	1.0
Two squares in perpendicular planes with a common side	0.20
Two equal, parallel squares separated by distance equal to side	0.19
Two equal, parallel circular disks separated by distance equal in diameter	0.18

A.6 Thermal Network

Figure A.1 provides a typical example of a thermal network. The thermal resistances due to conduction, convection and radiation are clearly shown. For this example, an ambient external temperature of 50ºC and 145 W of internal power dissipation is assumed. Note that printed wiring assemblies can have an operating ambient air temperature of almost 77ºC, or an internal temperature rise of 27ºC.

Many computer programs are available for modeling thermal networks. The modeling programs can do a steady state or transient analysis and can have thousands of nodes and thermal resistance values. Some examples of available programs are: MITAS, SYSCAP, and ANSYS. These programs run on mainframe computers and are available on most time share services throughout the country. Also, there are many similar versions of these programs which have been scaled down to run on micro and minicomputers.

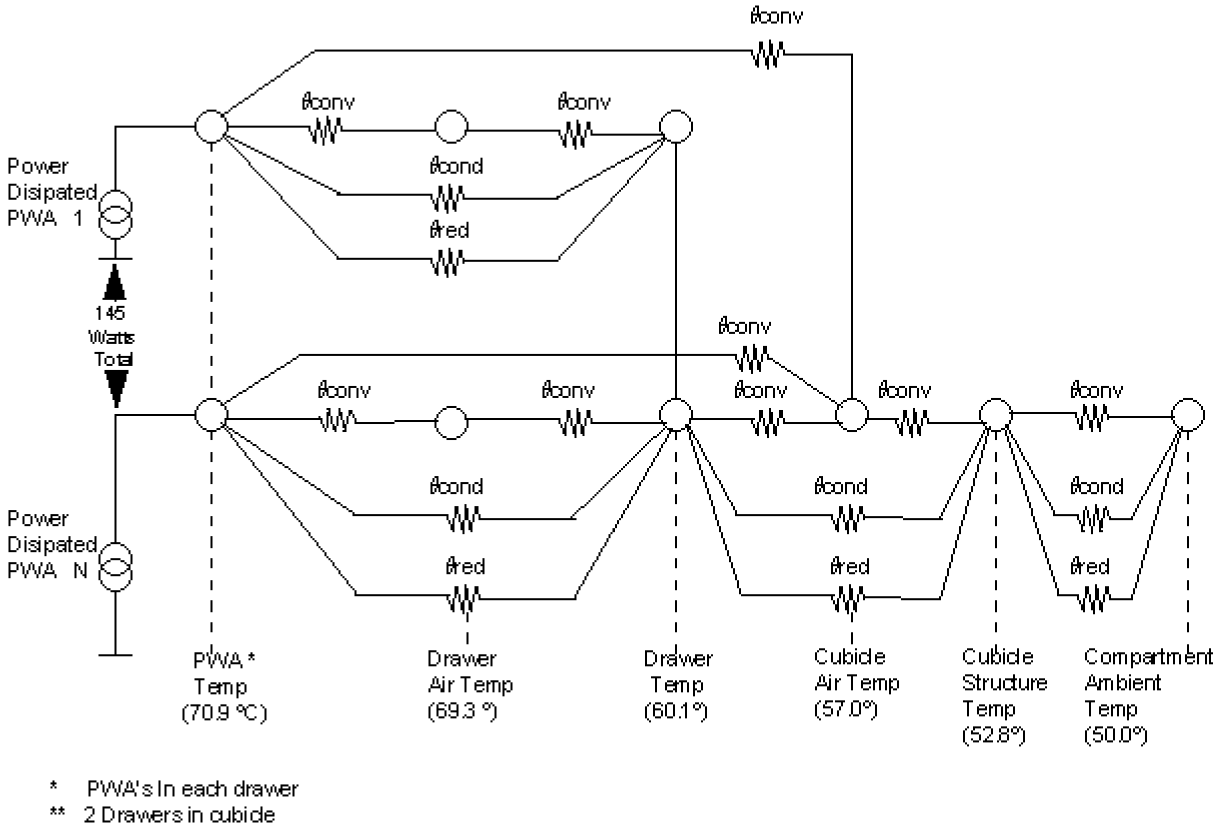

Figure A.1 -- Electronic Cabinet Thermal Network Example

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Appendix B -- Electrical Stress Derating Analysis

B.1 Introduction

The electrical stress derating analysis consists of determining, from the circuit and the operating conditions of a given application, the actual stresses induced on each part, the part's ability to withstand that stress at the part's operating temperature, and a comparison of that stress ratio to the derating requirements in this manual. These stresses are identified in terms of voltage, current, power, etc. Transient conditions must also be taken into account. The analysis will not normally consider worst case conditions with regard to applied voltages or currents, part parameter values, or driving signals. However, when an undesirable stress condition is noted, worst case conditions should be examined, and the probability of worst case occurrence investigated.

One of the objectives of a stress analysis is to provide early warning of design deficiencies at the program phase where changes are least expensive; that is, while the design is still on paper. A stress analysis incorporated early into a program can save significant amount of test time and dollars by providing a basis for a reliable design. Failures during a test program will inevitably cause delays in order to progress to the next acquisition phase, which is production.

B.2 Circuit Analysis

The purpose of a circuit analysis is to calculate the electrical parameters of each part in the circuit. These parameters can be AC/DC voltages and currents, peak or ripple voltages, transients, signal and power supply variations, etc. There are two ways of doing a circuit analysis: manual and computer aided.

In manual circuit analysis the engineer must calculate currents and voltages using basic circuit theory. This consists of using Ohm's law, Kirchoff's laws, Thevenin's Thermo, and equivalent network theory, just to name a few. This may be good for a small, simple circuit, but is too labor intensive and time consuming for most modern designs.

For large circuits, a computer-aided circuit analysis technique must be used. The computer generates a mathematical model of each component. It then arranges these models to fit the circuit, and steps through the analysis process. Currently, there are two well known computer-aided systems. They are SPICE, for Simulation Program for Integrated Circuit Evaluation, and SUPER COMPAC, for Super Computerized Optimization of Microwave Passive and Active Circuits.

The main advantages of a computer-aided system are speed and accuracy.

It can also be readily adapted to do worst case analysis. The effect of a part drifting out of spec, or its complete failure, can be simulated on the computer. Thus, the computer can assess its effect on the entire circuit. One, disadvantage, however, occurs when a semiconductor is not part of the program's database models. Then a model must first be developed by a design engineer before the computer can run.

B.3 Determining Part Stress Ratings

Part stress rating is defined as the ratio of applied to rated electrical parameters. These electrical parameters may consist of voltage, current, power, inverse voltage, etc., or any combination of these, depending on the part. For example, a power stress ratio is used for a resistor, while a voltage stress ratio is used for a capacitor.

A part's stress rating can vary from lot to lot, vendor to vendor, and usually decreases with increasing temperature. This appendix will concentrate on the latter -- how to calculate stress ratings with increasing temperatures. It will do this by presenting examples. For the purpose of these examples, it is assumed that a thermal profile analysis has already been done in accordance with Appendix B.

B.3.1 Examples

Example B-1: Application of a Solid Tantalum Capacitor Voltage Rating

1. ***Given:***

   a. Maximum equipment external ambient temperature profile is 70ºC.

   b. Derating requirement for equipment has been specified to be this manual.

   c. An equipment internal temperature rise of 30ºC has been determined, using the principles of Appendix B.

   d. Circuit requirement is 6.8 f, solid tantalum capacitor. Maximum impressed voltage is 10 VDC, determined from the electrical circuit analysis.

2. ***Determine***:

   The capacitor maximum voltage rating at the operating temperature.

3. ***Solution:***

   The part ambient operating temperature (T_{OP}) is the sum of the external ambient equipment temperature (70ºC) plus the internal temperature rise (30ºC) or:

   T_{OP} = 70ºC + 30ºC = 100ºC

From the absolute maximum part rating data for solid tantalum capacitors (Figure 200.8), we know graphically the maximum DC voltage rating at a part operating temperature of 100ºC has decreased to 87.25 percent of its maximum rating at 80ºC (reference Figure B.1). Analytically, we know:

$$V(\text{at } T_{op}) = V_{MAX}(\text{at } T_S)\ 100\% - \frac{100\% -- 66\%}{T_{MAX} - T_S}\,(T_{op} - T_S)$$

$$= V_{MAX}(\text{at } T_S)\ \frac{T_{MAX} - .33\,T_{OP} - .67\,T_S}{T_{MAX} - T_S}$$

$$V_{MAX}(\text{at } 100°\text{C}) = V_{MAX}(\text{at } 85°\text{C})\ \frac{35}{40}$$

$$= [.875]V_{MAX}$$

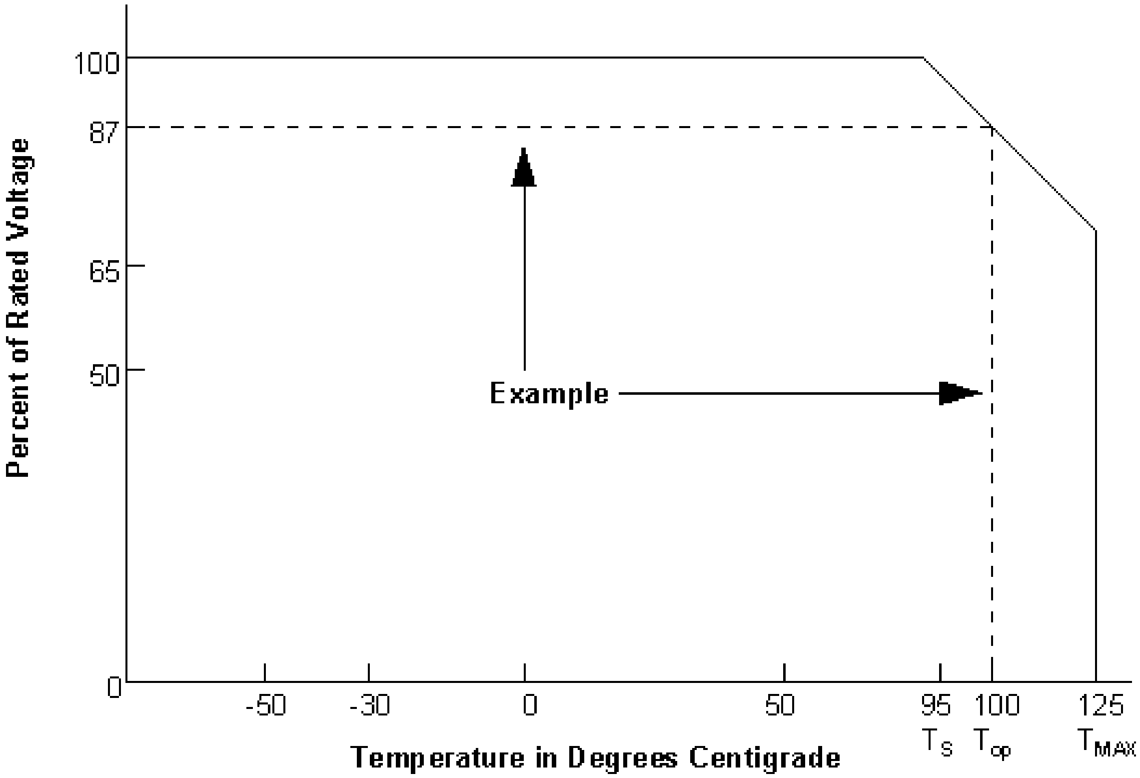

Figure B.1 -- Maximum Voltage Derating Curve

4. ***Determine:***

The required capacitor voltage rating for the application using the derating requirements in this manual for solid tantalum capacitors.

5. ***Solution:***

a. Part ambient operating temperature = 70ºC + 30º = 100ºC

b. Plot a vertical line from the 100ºC point on the temperature scale to the intersection of the derating curve (reference Figure B.2).

c. Plot a horizontal line from this point to the left hand scale.

d. Read: Maximum allowable impress voltage = .30 times the absolute maximum rating at 85ºC.

e. Calculate: 10 VDC/.3 = 33.3 VDC minimum rating required.

f. Use 35 volt rated, 6.8 f capacitor, quality level B.

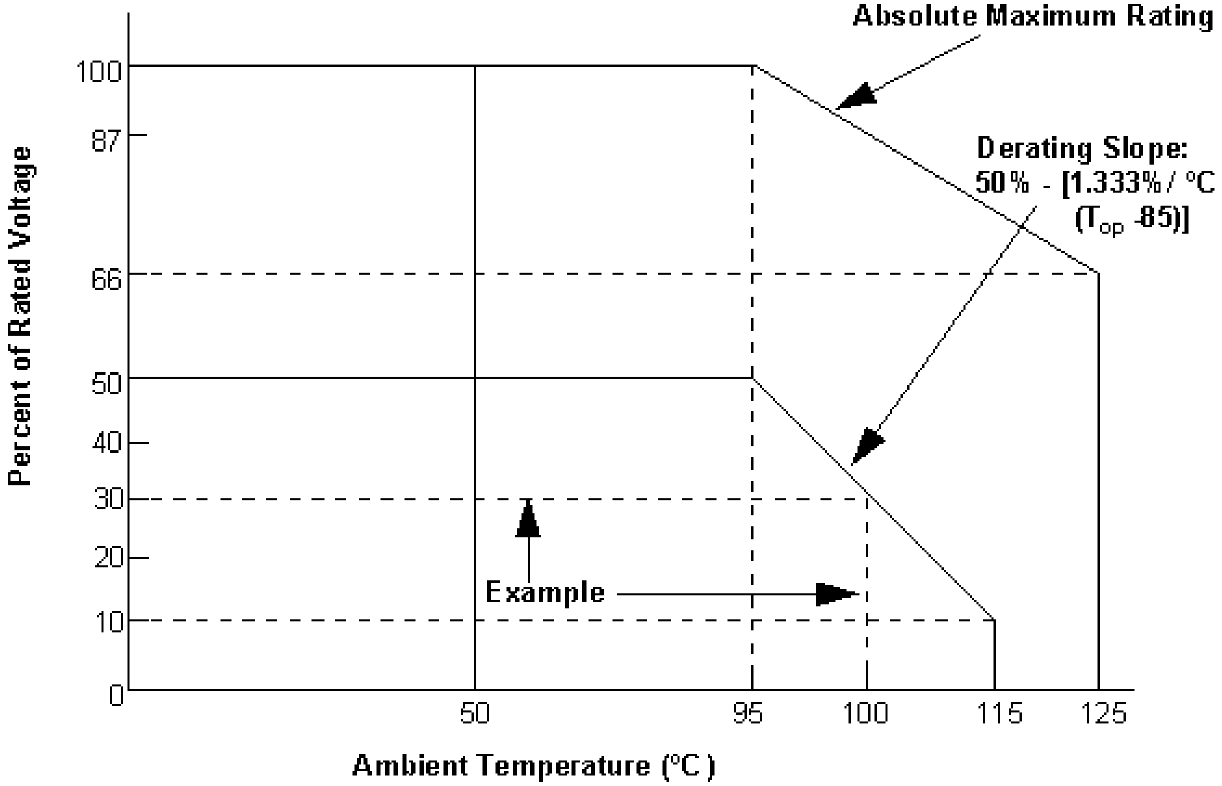

Figure B.2 -- Application of A Solid Tantalum Capacitor Derating Curve

<u>Example B-2</u>: Application of a Transistor -- Power Rating

1. ***Given:***

The general absolute maximum power rating and the derating requirements of this manual (reference Figure B.3).

2. ***Determine:***

Formula for the maximum permissible power dissipation at T_{JM} that meets the derating requirement for transistors in this manual.

a. From the device specification, determine the temperature at which power derating begins. This will be designated T_S.

b. From the device specification, determine the maximum rated junction temperature. This will be designated ^{T}JMAX.

c. Determine the maximum rated power at T_S from the device specification. This will be designated P_{MAX}.

d. The absolute maximum rating curve is now completely defined for the given device, (reference Figure B.3).

e. Determine T_D (derated maximum junction temperature).

For a derating of 50 percent:

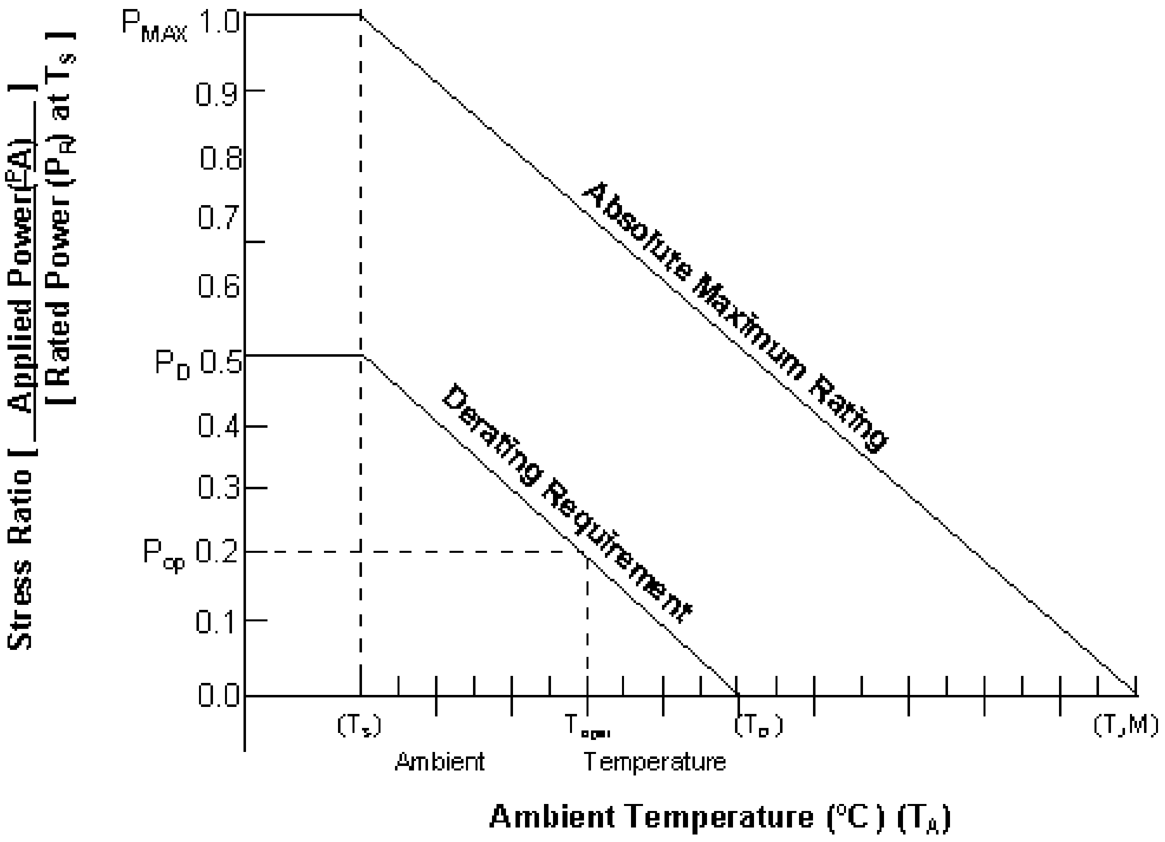

Figure B:3 -- Application of a Transistor Derating Curve

$$T_D \quad = \quad [T_{JMAX} - T_S) \text{ X } 50\%] + T_S$$

$$T_D \quad = \quad \frac{T_S + T_{JMAX}}{2}$$

f. Determine P_D (derated maximum power dissipation at 25ºC), which is 50 percent of P_{MAX} in this case.

g. The derating requirement curve is now completely defined for the given device (reference Figure B.3).

h. Determine the maximum operating air temperature (T_{OP}) to be encountered in the immediate vicinity of the part.

i. The following formula determines P_{OP}, the maximum permissible operating derated power dissipation, for the application.

$$P_{OP} = P_{MAX}. [(T_D -- T_{OP})(T_{JMAX} -- T_S)]$$

Note: This Derating Curve example is applicable to any semiconductor device by using the appropriate stress ratings and specifications for the given device.

The reader will observe the semiconductor derating requirement curve is parallel to the absolute maximum rated curve, whereas other device may display curves which are not parallel. For semiconductors, it can readily be confirmed that any curve parallel to the absolute maximum rating curve actually represents a semiconductor at a constant junction temperature.

To readily appreciate this phenomenon and gain familiarity with some of the terminology, the following semiconductor example is provided:

1. The maximum stress rating for a 2N917 will be utilized.

2. The transistor power derating curve to be utilized will be in consonance with the part derating requirements provided in Section 300.1 of this manual.

Maximum ratings selected from a 2N917 data sheet to develop the derating curve are now provided:

Power dissipation= P_D = 200 milliwatts at an ambient air temperature of 25ºC

Power derating = 1.14 mW/ºC above 25ºC air temperature

Thermal resistance θ_{JA} from the junction to air = .875ºC/mW

Note: The reciprocal of θ_{JA} equals the power derating; i.e.,

$$\frac{1}{.875°C/_{mW}} = 1.1\,mW/°C$$

The maximum junction temperature $T_{JMAX} = 200°C$.

The derating curve now appears as shown in Figure B.4:

Arbitrarily selecting two ambient air temperatures of 50ºC and 100ºC, the maximum derated permissible operating power dissipations (P_{OP}) are calculated to be:

$200mW \ x \ (112.5°C - 50°C)\ (200°C - 25°C) = 71\ mW$

and

$200(112.5 -- 100)\ (200-25)] = 14mW$.

For a 50ºC ambient temperature and an actual circuit application of 71mW power dissipation, the junction temperature would be

$T_J = T_A + (\theta_{JA}.\ P_D) = 50°C + (.875°C/mW)(71mW) = 112.5°C$.

For a 100ºC ambient temperature and an actual circuit application of 14 mW power dissipation, the junction temperature is:

$T_J = T_A + (\theta_{JA}.\ P_D) = 100 + (.875)(14) = 112.5°C$.

The reader can verify that for ambient temperatures greater than 25ºC, a “50 percent power derating” actually results in a junction temperature greater than 112.5ºC.

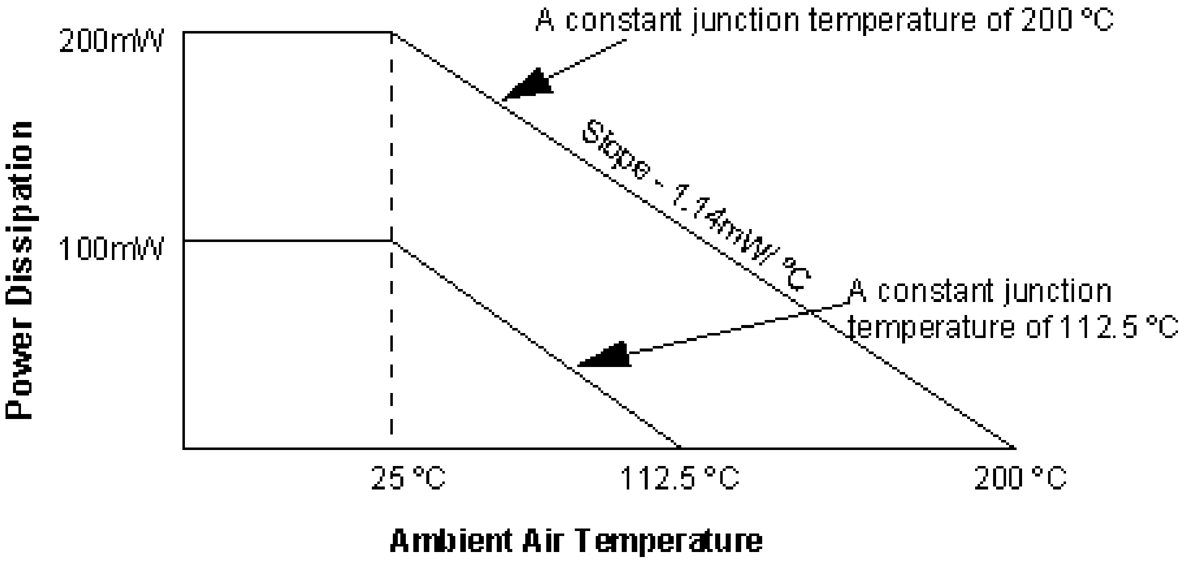

Figure B.4 -- Transistor Derating Curve

B.4 Documenting the Stress Analysis

The next step in the electrical stress derating analysis process is to calculate the stress ratios and document the results of the stress analysis. The stress ratio is the numeric ratio between the actual stresses determined from the circuit analysis divided by the stress rating of the part at the part operating temperature. This can be expressed mathematically as a percentage as follows:

$$\text{Stress Ratio (in \%)} = \frac{\textit{Applied Stress}}{\text{Stress Rating } (@\, T_{OP})} \times 100$$

Examples

Example B-3

Referring to Example B-1, the working voltage stress ratio and documentation of the analysis is presented on Stress Analysis Worksheets as Figure B.5.

Example B-4

Referring to Example B-2, the power stress ratio and documentation of the analysis is presented on Stress Analysis Worksheets as Figure B.6.

B.5 Example Worksheets

In general, the best method of stress analysis documentation is to utilize worksheets that allow for a logical flow of information from left to right with all required data and parameters specifically called out in a column callout. This obviates the casual omission of required parameters and is most effectively accomplished with the use of different worksheets for the various part categories.

Documentation of any electrical stress analysis should be to a level sufficient to accomplish the following in descending order of importance.

1. To assure the designer that all derating parameters required by this manual have been reviewed and the derating requirements met.
2. To assure that the contractor can verify compliance to the derating requirements in this manual during formal and informal design reviews.
3. To any additional level required to provide data required by the Contract Data Requirements List, DD-1423.

An example collection of Part Usage and Applied Stress Data Worksheets are included herein.

B.6 Derating Verification

Verification of the derating requirements is accomplished by comparing the actual stress ratios to the maximum allowable stress ratio as provided in the derating requirements of this manual.

If all parameters contained in the part derating requirements have not been addressed for each and every part type, the Electrical Stress Derating Analysis has not been satisfactorily completed.

A major pitfall is that some contractors review only those stress parameters required to perform a failure rate prediction. As a result, many of the parameters contained in the derating requirements of this manual are not addressed. Electrical Stress Derating Analyses that address only the parameters necessary for failure rate prediction should be rejected.

If all the derating requirements contained in Table I of Section I have been addressed and met, the baseline design has been established.

If the derating requirements have not been met, the Electrical Stress Derating Analysis must contain trade-off studies which bring the baseline design within the derating requirements, or engineering justification demonstrating why they cannot be met. One of the most important elements in requiring an Electrical Stress Derating Analysis is to allow for Navy review of any the contractor justification of stresses which do not comply with the derating criteria and determine if there is agreement with the justification.

See Hard Copy for Figures B.5 Through B.11

Figure B.5 -- Part Usage and Applied Stress Data Capacitors Fixed and Variable

Figure B.6 -- Part Usage and Applied Stress Data Transistors

Figuer B.7 -- Part Usage and Applied Stress Data Resistors Fixed

Figure B.8 -- Part Usate and Applied Stress Data Relays

Figure B.9 -- Part Usage and Applied Stress Data Diaode -- Zener

Figure B.10 -- Part Usage and Applied Stress Data Diodes Signal, General Purpose and Recitifier

Figure B.11 -- Part Usage and Applied Stress Data Linear Microcircuit

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Appendix C -- Factors Affecting Failure Rates of Parts

C.1 General

The following tables give the factors affecting the failure rates of electrical/electronic parts. As given in MIL-HDBK-217 the part failure rate is a function of these factors (designated as ““factors). An asterisk appearing in any column indicates that those factors do not contribute to the failure rate of the particular part type:

For example, the part failure rate p for fixed resistors is given by:

λp = $\lambda b(\pi E\ ^{x}\ \pi R\ ^{x}\ \pi Q)$

Where λb = base failure rate (a function of temperature and stress)

πE = Environmental factor

πR = Resistance factor

πQ = Quality factor

Table C.1 -- Factors Affecting Failure Rate

Device Type	**Temperature**	**Environment**	**Quality Level**	**Stress** Ratio**
Resistors	**X**	**X**	**X**	**X**
Capacitors	**X**	**X**	**X**	**X**
Semiconductors	***X***	***X***	***X***	***X***
Microcircuits	X	X	X	2*
Relays	X	X	X	2*
Connectors	X	X	*2	2*
Switches	X	X	2*	X
Inductive Devices	X	X	2*	X

* Power for resistors
Voltage for capacitors
Power (current) for semiconductor devices
Power, current (continuous) for microcircuits
Contact current (continuous) for relays
Contact current and voltage for switches

** Due to a lack of statistical data MIL-HDBK-217 failure rates do not consider all the electrical parameters affecting part failure rate. Also MIL-HDBK-217 does not consider the effect of transients on failure rate. For a more complete listing of factors which affect part reliability, see Table 1 of Chapter 1.

** See note 1 on page C-2.

C.2 Failure Rate Factors Unique to Different Devices

Table C.2 -- Resistors

Resistor Type	**Resistance[3] Value**	**Number of Taps on Potentiometer**	**Voltage Factor**	**Construction**	**Number of Resistors in Use**
Fixed	X				
Variable	X	X	X		
Variable (Styles RP and RR only)	X	X	X	X	
Resistor Network (Style RZ)					X

1 Power for resistors
Voltage for capacitors
Power (current) for semiconductor devices
Power, current (continuous) for microcircuits
Contact current (continuous) for relays
Contact current and voltage for switches

2 Due to a lack of statistical data MIL-HDBK-217 failure rates do not consider all the electrical parameters affecting part failure rate. Also MIL-HDBK-217 does not consider the effect of transients on failure rate. For a more complete listing of factors which affect part reliability, see Table 1 of Chapter 1.

3 The higher the resistance value, the higher the failure rate.

Table C.3 -- Capacitors

Capacitance values -- all styles except CV, PC, CT and CG. (The higher the capacitance value, the higher the failure rate)

Series circuit resistance -- for type CSR. (The higher the series circuit resistance, the lower the failure rate)

Construction -- for type CLR only.

Configuration -- for type CG only.

Table C.4 -- Relays, Switches and Connectors

Device Type	**Number of Contacts**	**Time Rate of Actuation**	**Contact Load**	**Construction and Application**
Relays	X	X	X	X
Switches	X	X	X	
Connectors	X	X		X

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Appendix D -- Derating

D.1 General

This appendix explains the reason derating is required on electronic parts. The definition of derating is: the application of parts in such a manner that the actual stresses are substantially less than the design maximum ratings. Design maximum ratings usually relate to the maximum rating given to a part by the manufacturer. The closer a part is operated to its design maximum ratings, the greater the probability of failure. Derating reduces the probability of failure. It also allows added protection from system anomalies unforeseen by the designer (e.g. transients). Derating is a well known and commonly practiced procedure, and is one of the most powerful reliability tools available to the designer.

D.2 Derating Theory

A part's strength varies from lot to lot and from one manufacturer to another. This is a random process and can therefore be represented by a statistical distribution. Likewise, the stress on a part is random. It changes with temperature, vibration, electrical transients, vibration, shock, etc. Stress can also be represented by a statistical distribution. Figure D.1 is a graph showing strength and stress distributions together. Each statistical distribution is represented by a probability density function. The average value is the highest point on the curve, and it gradually diminishes at the same rate on either side of the average.

For a part to operate properly, the strength must be higher than the stress. However, since strength and stress are both random, there is always a slight chance that stress will be higher than strength. It is represented by the intersecting (shaded) area of the graph. The larger the intersection area, the higher the failure rate becomes.

The intersecting area can be decreased by two methods:

(1) decrease the stress on a part (which moves the stress distribution to the left), or

(2) increase the part's strength (which moves the strength distribution to the right). In either case, or both, the goal is to decrease the parts stress-to- strength ratio. The degree to which the stress-to-strength ratio affects the random failure rate is well known and is published in MIL-HDBK-217.

Basically, MIL-HDBK-217 is a listing of the intersecting areas for different parts under different stresses. From MIL-HDBK-217 one can plot failure rate vs. stress level for various temperatures. An example is shown in Figure D.2. It is readily apparent from this graph that failure rate increases exponentially with stress. It can also be readily shown that failure rates increase exponentially with temperature (see Figure D.3). Therefore, by setting temperature and stress limits one can decrease failure rates exponentially. Ideally, these limits should be set at a point where the rate of increase of failure rate is above an acceptable amount. In other words, where the slope of the line becomes too steep. This is how the derating curves in this manual were derived.

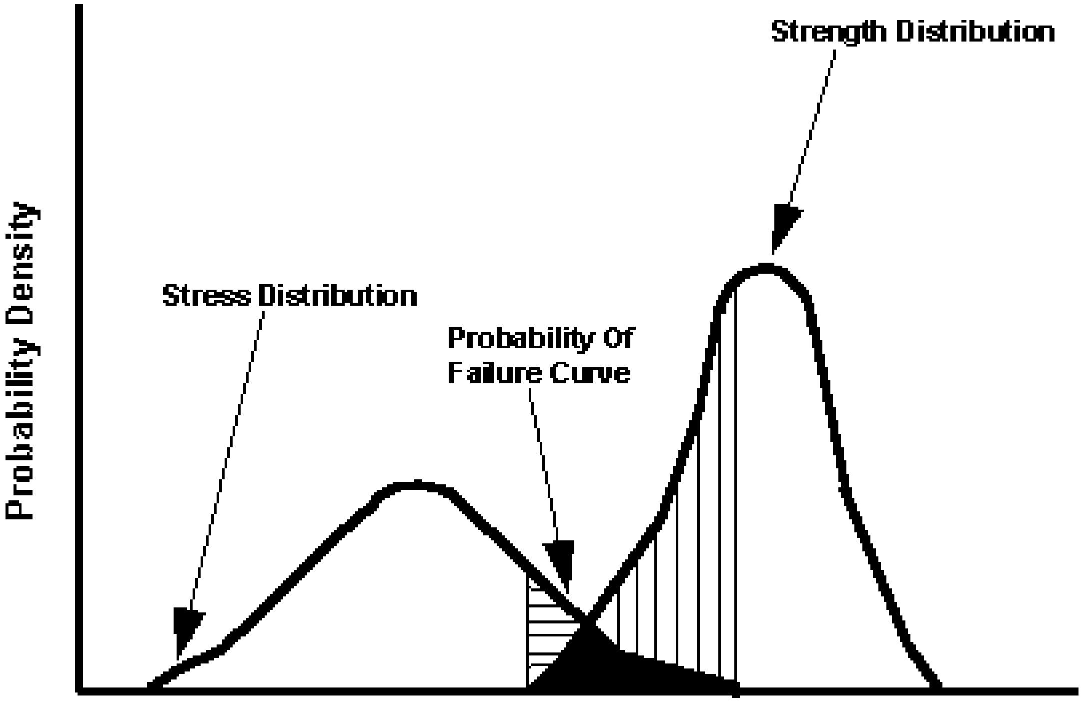

Figure D.1 -- Strength-Stress Parameter

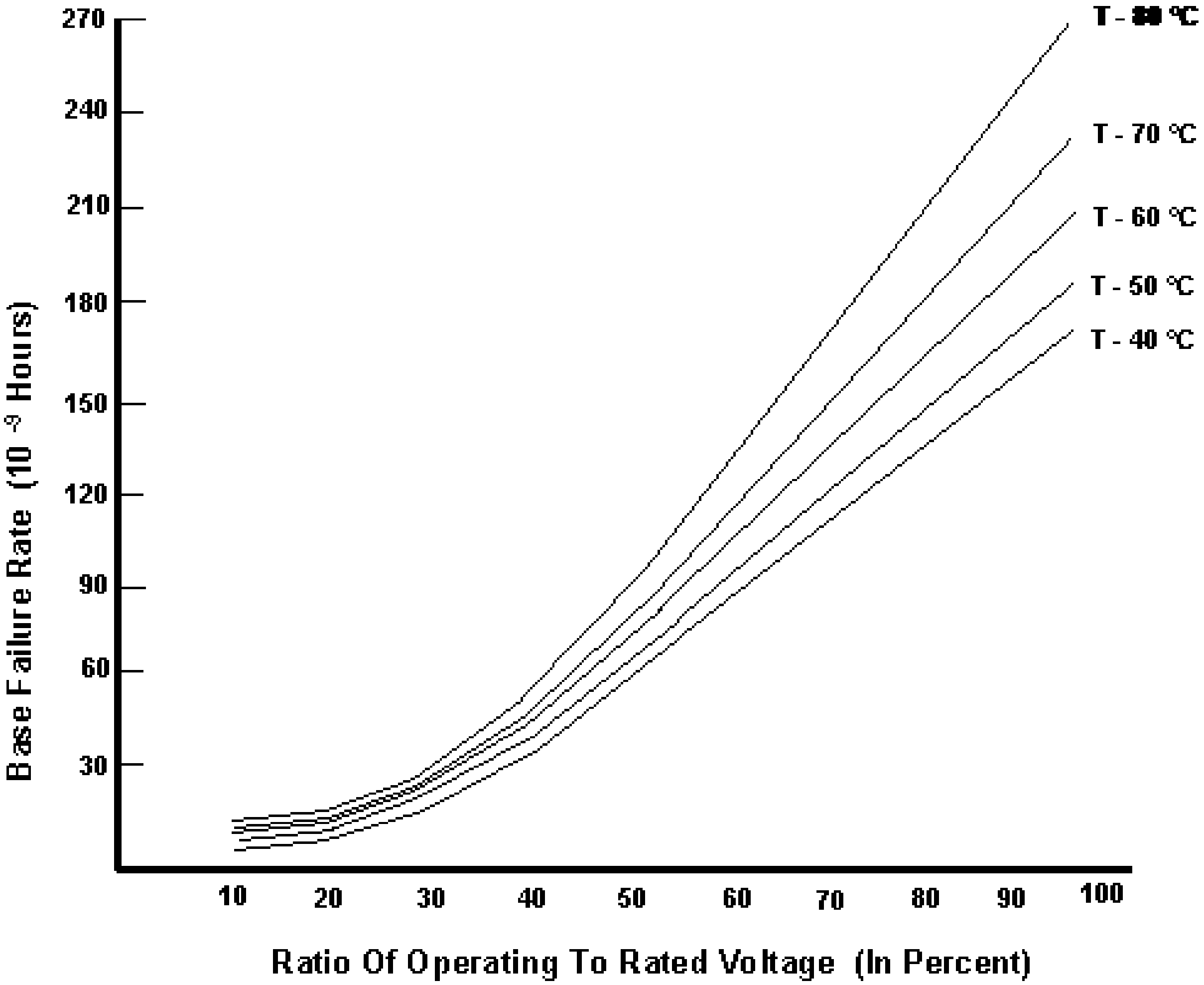

Figure D.2 -- Failure Rate vs. Stress Ratio With Temperature as Parametric Variable

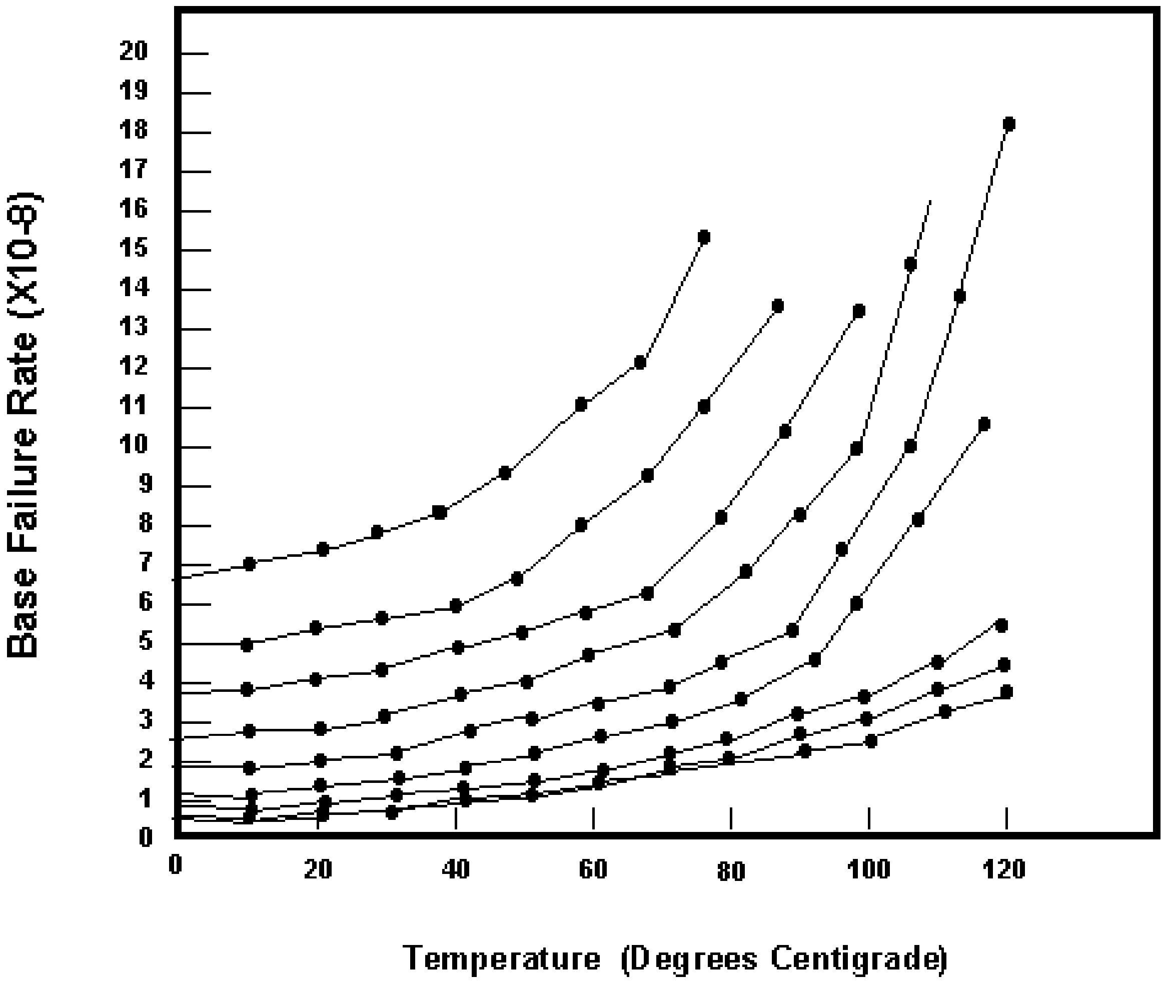

Figure D.3 -- Failure Rate vs. Temperature for a Capacitor With Stress as Parametric Variable

In most instances stress cannot be reduced without a change in the electrical design. Therefore, the most common approach is to increase the part's strength. This is done by using a larger or stronger part. The part can then be stressed to only a small percentage of its capability. This is analogous to using safety factors in mechanical designs. The higher the safety factor, the stronger the end item will be.

As a side benefit, derating also reduces part internal operating temperature. This decreases the rate of chemical time-temperature reactions, which are the primary cause of part aging and parameter drifting.

Different part types are failure sensitive to different types of environmental and electrical stresses. A capacitor, for instance, is primarily sensitive to voltage, while a diode is sensitive to power, forward current, and reverse breakdown voltage. These are the stresses a particular part must be derated to. Some stresses can be derated directly. Other stresses are depended on temperature. Therefore, their derating requirements must also be dependent on temperature. For example, a type CUR13 capacitor (p. 200-28) has its voltage derated by a constant 60 percent up to 105 degrees C. A type CB50 capacitor (p. 200-29), however, is derated by anywhere between 55 and 40 percent, depending on its operating temperature.

D.3 Example

The following is an example of how the absolute maximum and derated maximum power limits are calculated for a MIL-R-55182 resistor.

The absolute maximum rating line for a MIL-R-55182 resistor (style RNR) is shown in Figure D.4. Along the absolute maximum rating line the resistor is operating at 100 percent of its capability. Below 125 degrees C the resistor is capable of operating at full wattage. Above 125 degrees C, the absolute maximum wattage rating is reduced linearly. It reaches zero at 175 degrees C. The absolute maximum rating of a 0.125 watt resistor used at 140 degrees C is 70 percent of its maximum, or 0.0875 watts.

The derating curve of a MIL-R-55182 resistor is also shown in Figure D.4. As can be seen, it is parallel to the absolute maximum rating line. It is derated to 55 percent of maximum up to 125 degrees C. Above 125 degrees C, it is reduced linearly and reaches zero at 150 degrees C.

When derated, the resistor cannot operate above 150 degrees C. At 125 degrees C,

the same 0.125 watt RNR resistor should not dissipate more than 0.069 watts. Likewise, at 140 degrees C it should not dissipate more than 0.019 watts.

Figure D4 Not Provided

Figure D.4 -- Derating Curves for RNR Style Resistors

D.3 Tradeoff Considerations

There may be circumstance where the full derating requirements in this manual are not desired. However, any deviation from the requirements in this manual must receive approval from the Procuring Activity.

The reason full derating may not be desired is because derating requires tradeoffs in other areas. For instance, for a circuit to meet derating requirements it must be made more complex. Where one part could do the job, now two parts must be used. This increased complexity increases space and weight. Also, full derating may not be desired for one-shot devices, such as missiles or torpedoes. If the device's operating life is only a few minutes, derating will not be very effective. However, in these circumstances one must also take into account if the one-shot device receives any operational testing, or can stay in a stand-by mode for long periods of time.

The degree to which derating is applied should be weighed against the impact on mission performance in the event of system failure, as well as space and weight considerations.

In these circumstances, full derating requirements may have to be sacrificed. However, rather than completely eliminating derating requirements a tradeoff can be made. This manual is written so it can be tailored to different applications. A statement in the contract stating that the derating requirements be decreased by a certain percentage would suffice.

D.4 Circuit/Part Tolerance

Although derating will increase the life of a part, failure rates will vary widely depending on circuit application and part parameter drift. To assure low failure rates, designers should strive to make circuits as tolerant as possible to part parameter variations. Although part specifications control the amount of parameter drift parts can undergo as a result of artificial aging and environmental exposure, individual parts may vary more. Unless the circuit design is sufficiently tolerant, the circuit may not function properly, even though no catastrophic part failure has occurred. Extreme examples of poor design are those circuits which require part selection for proper operation.

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Appendix E

Standard Electronic Module Program

E.1 General

The purpose of the Standard Electronic Module (SEM) program is to take many electronic functions and combine them into one electronic module. The program uses quality assurance techniques, high quality parts, derating, and detailed thermal analysis to make a highly reliable product. The intent of the SEM program is to make the modules more reliable and less costly than their individual parts put together.

The SEM program is operated by Naval Avionics Center (NAC), Indianapolis, Indiana, and Naval Weapons Support Center (NWSC), Crane, Indiana. NAC is the SEM program Design Review Activity (DRA). Its responsibilities are to review new modules and applications to a particular system, recommend methods of optimizing design, determine whether new modules should become “standard”, assign module key codes and drawing numbers, and maintain module data banks. NWSC, Crane is the Quality Assurance Activity (QAA). Its responsibilities are to review new module specifications, do initial qualification design reviews, correlate vendor test equipment with bench test setup equipment, review failure trends, perform failure analysis, and conduct process audits.

E.2 Program Objectives

The basic objectives of the SEM program are to:

1. Divide electronic functions into building blocks that can be used in many different applications.
2. Lessen dependence on a specific vendor’s design or manufacturing technology. The intent of this objective is to save cost through vendor innovation and competition.
3. Achieve high reliability through the use of high quality parts.
4. Provide thermal design limits (e.g., 60_ C Class I, 100_ C Class II maximum fin temperature).
5. Achieve replace-upon-failure maintenance policy.
6. Assure that environmental requirements are at least as severe as actual use environments.
7. Provide flexible mechanical packaging requirements which can accommodate many different circuit applications.

8. Ease the logistics support burden on the supply system by combining many common functions into a limited number of modules.

There are about 350 standard modules presently in existence. To maintain package configurations, specially designed SEMs are allowed for special functions. These special SEMs are only allowed for functions not currently available, and they are required to meet the same quality assurance requirements as the standard SEMs. Special SEMs expected to have common usage in future equipment and can be changed to standard SEMs.

Figure E.1 depicts the quality assurance activity. It begins in the design phase and continues through design verification, production, and use. Quality assurance is implemented through auditing and failure analysis reviews.

The Military Specifications pertinent to the SEM program are shown in Figure E.2.

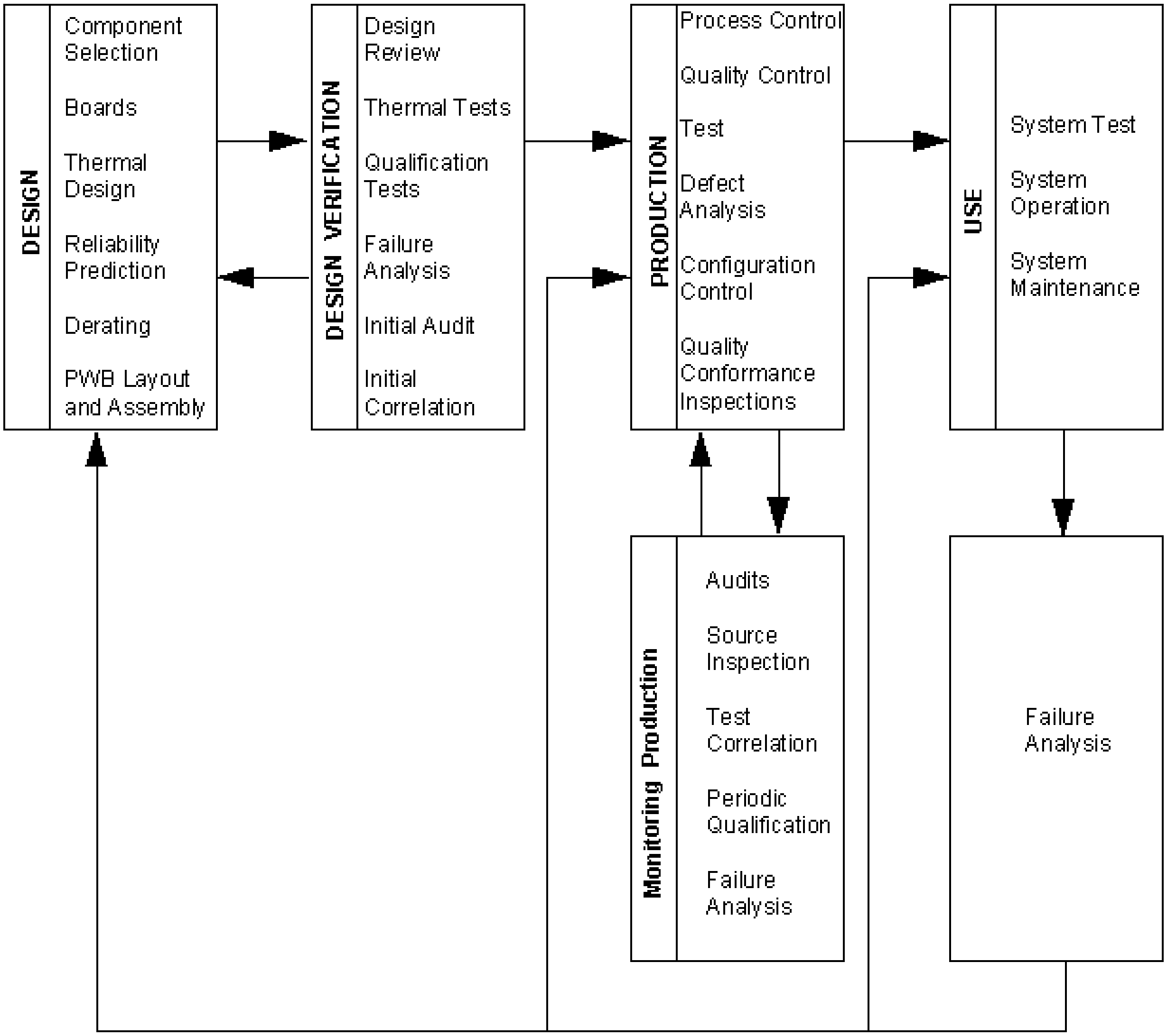

Figure E.1 -- QA Process

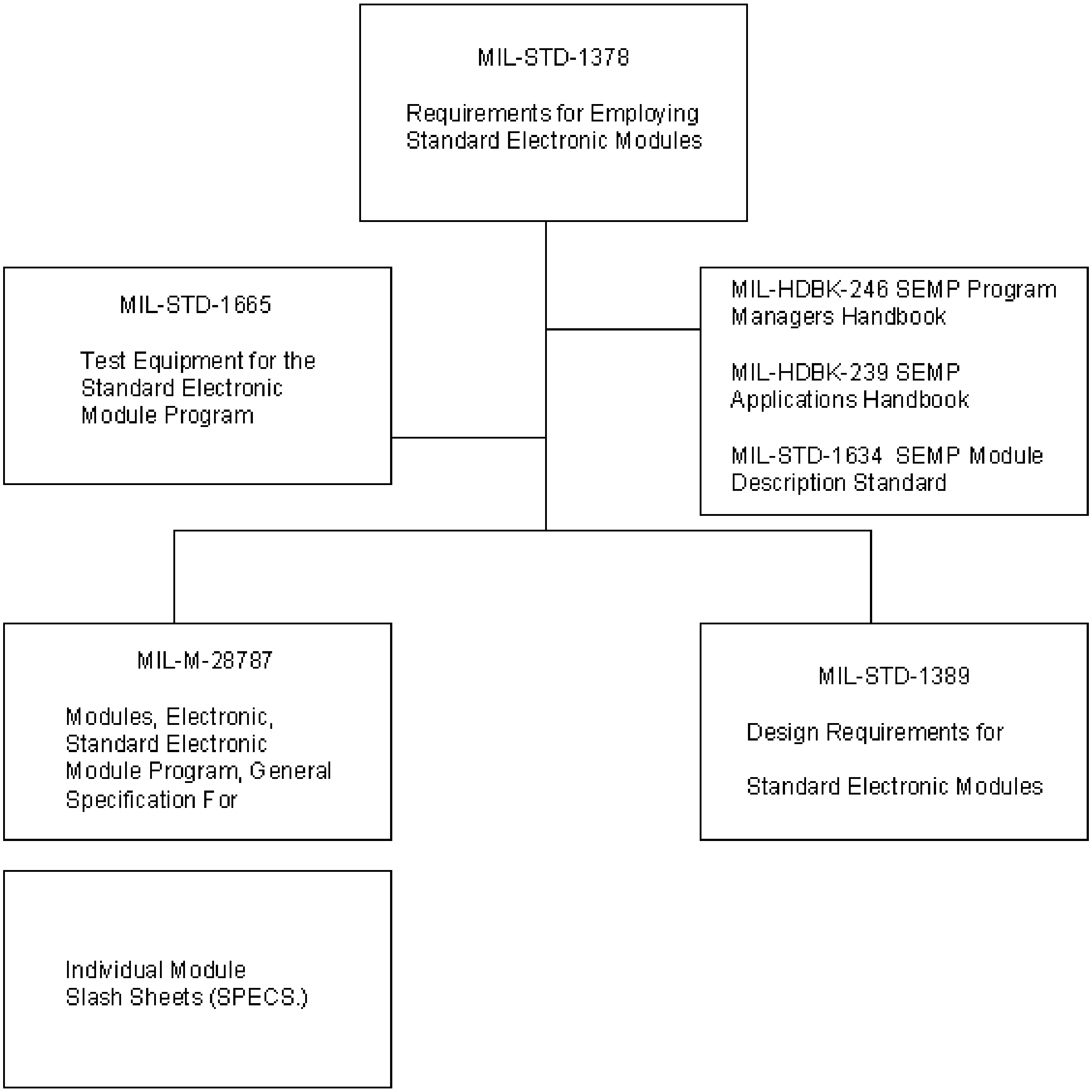

Figure E.2 -- Military Specifications Pertinent to SEM Program

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Appendix F -- Transient Suppressors

F.1 General

A transient is a short duration change, either positive or negative, in current or voltage. Transients of major concern, from a damage standpoint, are positive transients, which can exceed device capability, although negative transients can induce system malfunctions by disrupting logic systems, loss of servo system control, etc. Transients can cause slow degradation, erratic operation, or catastrophic failure in electrical parts, insulation dielectrics, and electrical contacts used in switches and relays. The possible occurrence of transients must be considered in the overall electronic design. Required circuit performance and reliability must be assured both during and after the transient.

Table F-I -- Transient Sources

Man-Made

- Switching (mechanical and solid state) of reactive loads; opening and closing of switches and relays
- Fuse and circuit breaker interruptions and resettings.
- Generator and motor operation (overspeed and hunting, startup, control and shutdown).
- Ignition system, arc welder, particle precipitator operation.
- Fluorescent light operation.
- Reflected waves.
- Electromagnetic pulse (EMP), e.g., from nuclear blasts, large chemical explosions.
- Current inrush.
- Thyristor switching power control.

Natural

- Lightning.

Transients originate from three major sources; normal switching operations (power supply turn-on and turn-off cycles), routine AC line fluctuations, and abrupt circuit disturbances (faults, load switching, voltage dips, magnetic coupling by electro-mechanical devices, lightning surges, etc.)

Transients are a major cause of component failures in seminconductors. Random transients can permanently damage voltage sensitive devices and disrupt proper system operation. Normal shipboard power system on-off cycles have the potential of emitting spikes with enough energy to destroy an entire semiconductor device chain. Any surviving devices are also suspect. Trouble shooting, isolation, and replacing damaged devices is both time consuming and costly. This is especially true in the field. Transients are fairly common on shipboard power systems. As described in DOD-STD-1399 (NAVY), Section 300, shipboard power systems may encounter many types of voltage transients depending upon the type of power system.

F.1.1 Power System Types

F.1.1.1 Shipboard Power Systems:

There are three different types of power systems used in shipboard applications are:

1. ***Type I*** -- 400/115 V (rms), 60 Hz, at either 3 phase or 1 phase. This is used mainly for ship's servicing power and lighting distribution system. Voltage tolerance is ±5 percent of the average of the three line to line voltages.

2. ***Type II*** -- 440 or 115 volts (rms), 400 Hz, at either 1 phase or 3 phase. The voltage tolerance is not as precise as Type III systems.

3. ***Type III*** -- 440 or 115 volt (rms), 400 Hz, 3-wire, or 115 volt (rms) 4-wire. This is similar to Type II except the average voltage tolerance between line to line is ±1/2 percent.

F.1.1.2 Aircraft Power Systems:

These are characterized by:

1. AC power: AC Power is available as single phase or three phase wye-connected neutral or ground return system having a nominal voltage of 115/200 VAC and a nominal frequency of 393/407 Hz. The only alternate standard is a nominal 230/400 VAC when specifically authorized. The voltage unbalance will be a maximum of 3.0 volts, and the waveform distortion factor will be 0.05 maximum. The maximum frequency drift rate will be 15 Hz per minute. In emergency situations, where the limited power available is necessary to operate flight controls and communications, the steady state voltage and frequency will be maintained between 104 and 122 VAC and 360 to 440 Hz.

2. DC power: DC Power is available as two-wire or ground return systems at a nominal 28 VDC and, when specifically authorized, 270 VDC. These busses are maintained between 22 and 29 VDC and between 250 and 280 VDC respectively. Because of the overall advantages of the 270 volt distribution system, is expected that this system will become more and more common. Most aircraft provide two 28-volt and one 270-volt bus.

> The distortion factor (the ratio of the rms value of the superimposed ac ripple to the average DC voltage) for the 28 volt bus is 0.035 maximum, and the distortion factor for the 270 volt bus is 0.008 maximum. Maximum ripple voltage will be 1.5 volts on the 28 volt system and 6.0 volts on the 270 volt system. In emergency situations, where the limited power available is needed for weapons jettison and aircraft control, steady state voltages will be within the limits of 16 to 29 VDC on the 28 volt bus, and 240 to 290 VDC on the 270 volt bus."

F.1.2 Power System Transients

F.1.2.1 Shipboard:

For Type I and Type II power supply systems, voltage transients of 10 percent or less may occur several times an hour, and transients of 10 to 16 percent may occur several times a day (percentage based on nominal user voltage). On Type I systems, the time to reach the transient maximum varies from 0.001 to 0.03 second, and to reach the transient minimum from 0.001 to 0.06 seconds. This depends on the rating of the generator and the type of regulator and excitation system used.

For Type III power supply system, voltage transients of 1 percent or less may occur several times an hour. The time to reach the transient maximum may vary from 0.001 to 0.1 second.

F.1.2.2 Aircraft:

Aircraft power transients are required to be capable of tolerating transient variations in both voltage and frequency values. Figures F1 to F5, taken from MIL-STD-704, provide limit envelopes for application to aircraft power.

F.1.3 Shipboard Equipment Transient Protection

Some system protection is normally built into shipboard equipment, but this protection will not always prevent damage. The equipment is still susceptible to high frequency, high voltage transients. These can occur from electromagnetic pulses, lightning, static discharges, switching of low factor loads, switching from normal to alternate power supplies, or active ground detector tests (an active ground detector superimposes 500 V DC on an AC system).

F.2 Common Sources of High Frequency Transients

F.2.1 Lightning

A single lightning can have a length of over 2 Km and a peak current up to 400 KA. Lightning usually occurs in two or three strokes, but can vary anywhere between one to twelve. The rise time for the first return stroke is about 1.5 s with decay to 1/2 crest value of 40 s. The highest peak currents (i.e. 400 kA) occur in the tropical regions of the world, because of the greater height of the thundercloud. Maximum peak currents in the temperate zones are about 250 kA.

The initial phase of a lightning discharge begins with a downward moving stepped leader. This is when the electric field between the thundercloud and the earth is sufficient to cause dielectric breakdown of the intervening air. The stepped leader lowers the cloud to ground charge inincremental steps. It ionizes a channel which becomes the path of the lightning stroke. After the channel is generated, the return stroke travels from ground up to the base of the cloud. Although the stroke travels from earth to cloud, the charge transfer of electrons is normally from cloud to earth.

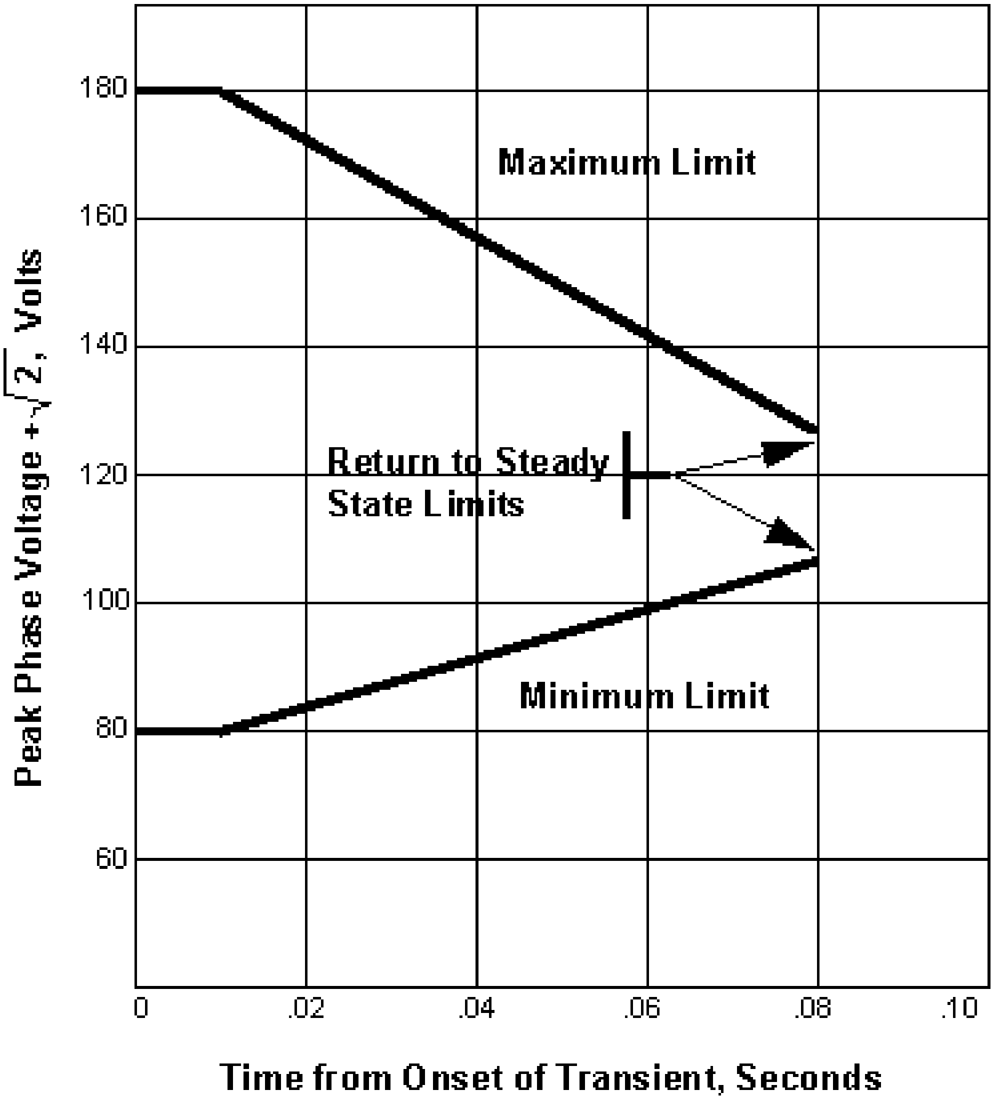

Figure F.1 -- Envelope of AC Voltage Transient for Aircraft Power Systems

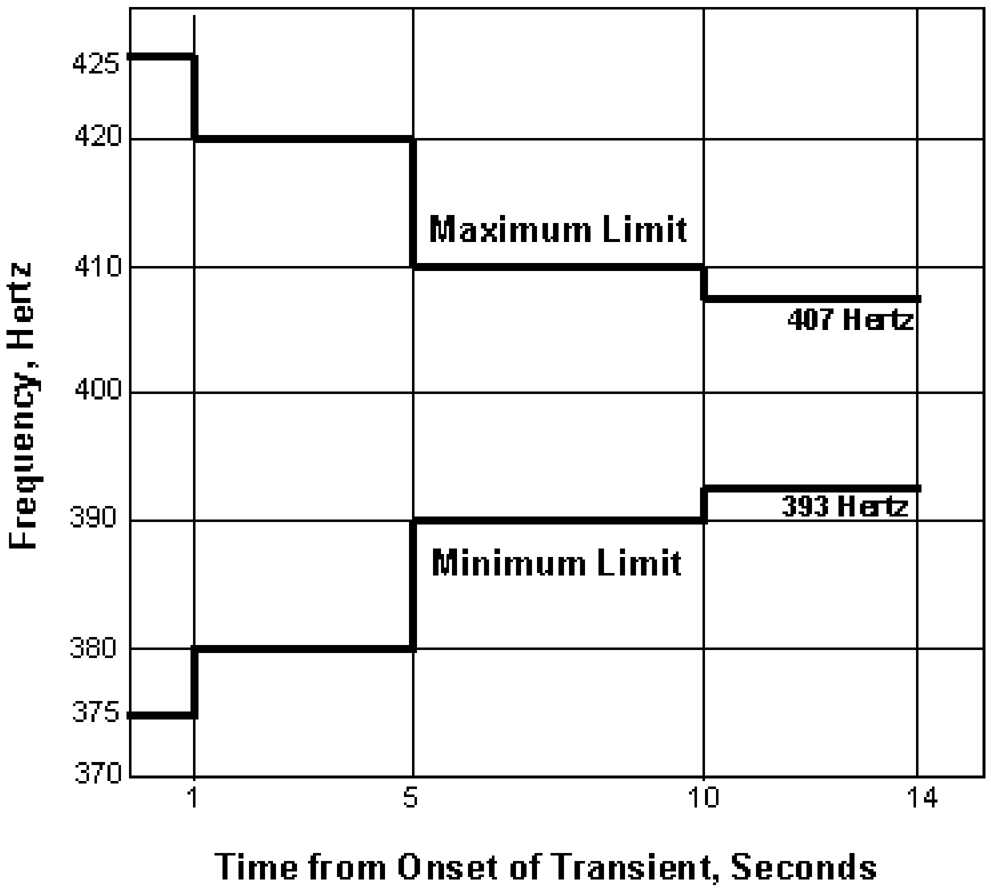

Figure F.2 -- Envelope for AC Frequency Transient for Aircraft Power Systems

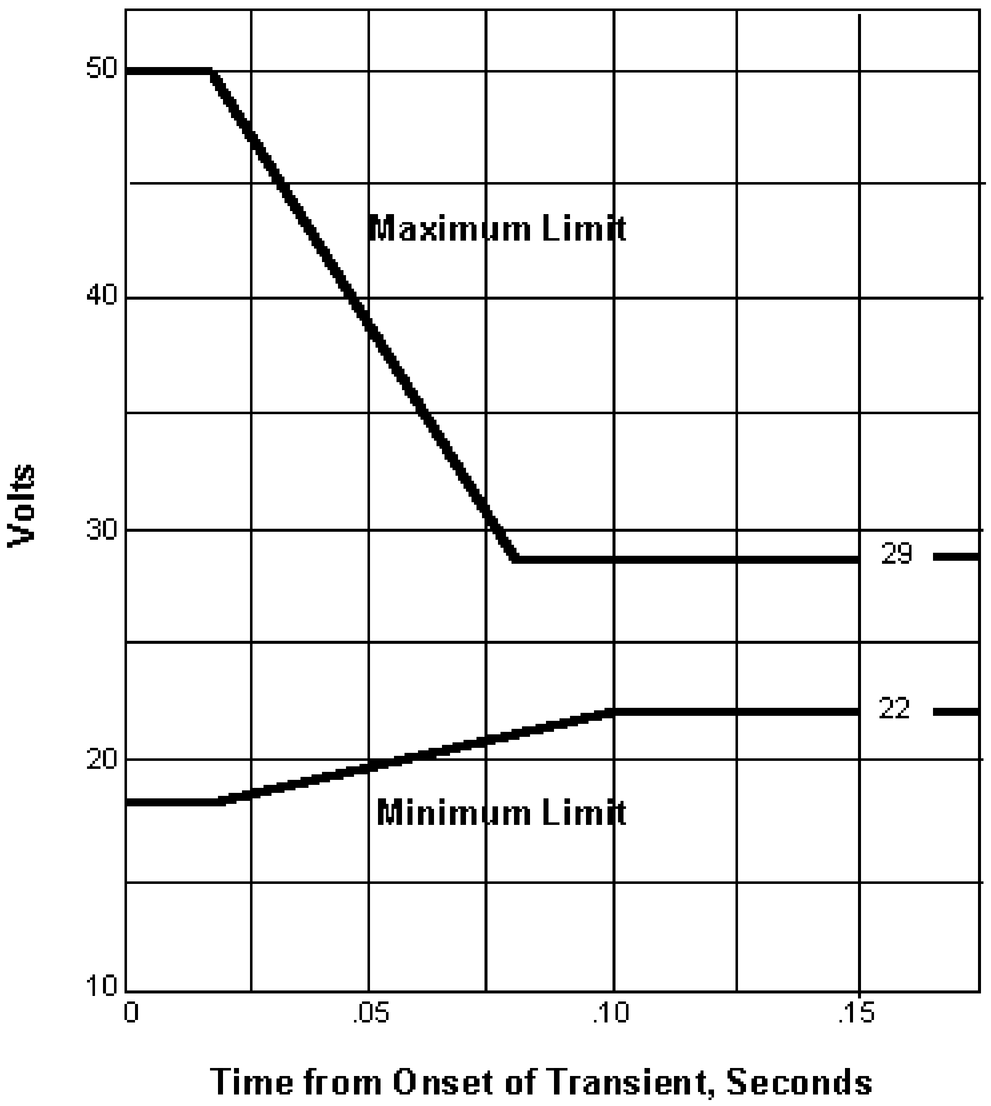

Figure F.3 -- Envelope for Voltage Transient for 28 Volts (Nominal) DC System

Note: Limits shown do not apply to voltage spikes having a duration of less than 50 microseconds. These are controlled by MIL-E-6051

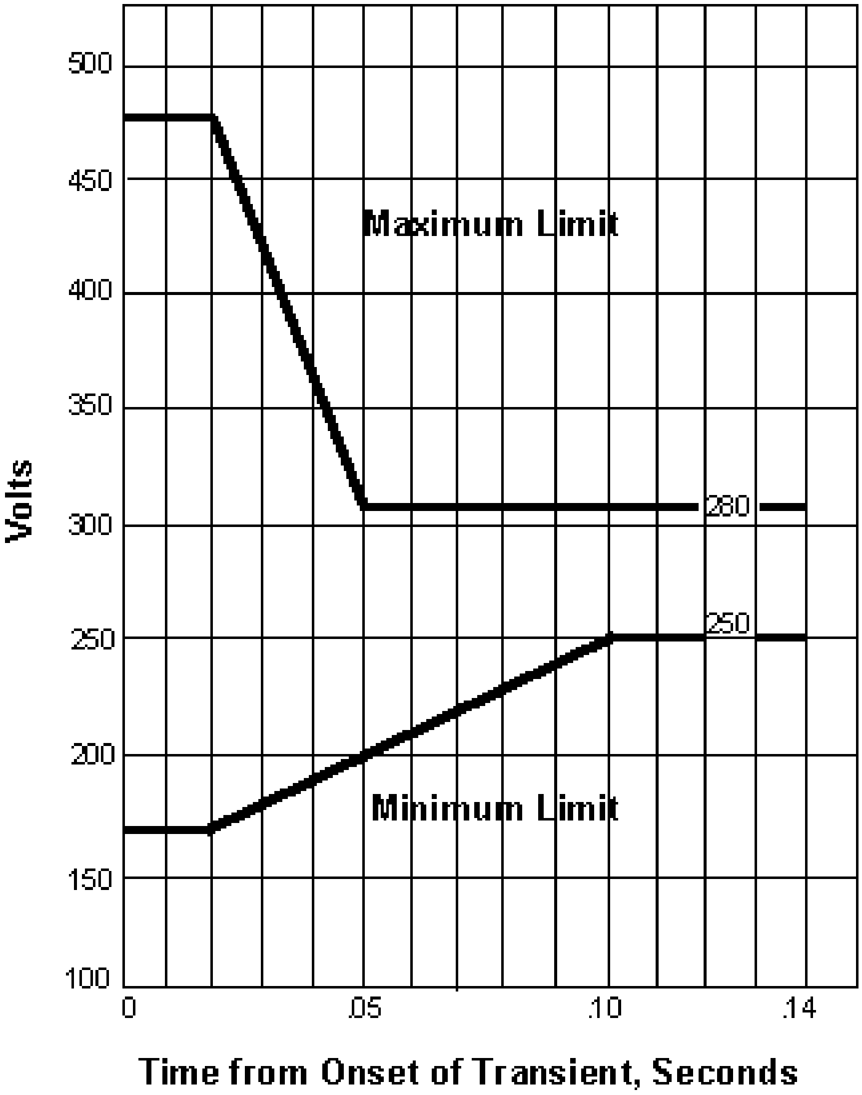

Figure F.4 -- Envelope for Voltage Transient for 270 Volts (Nominal) DC System

Note: Limits shown do not apply to voltage spikes having a duration of less than 50 microseconds. These are controlled by MIL-E-6051

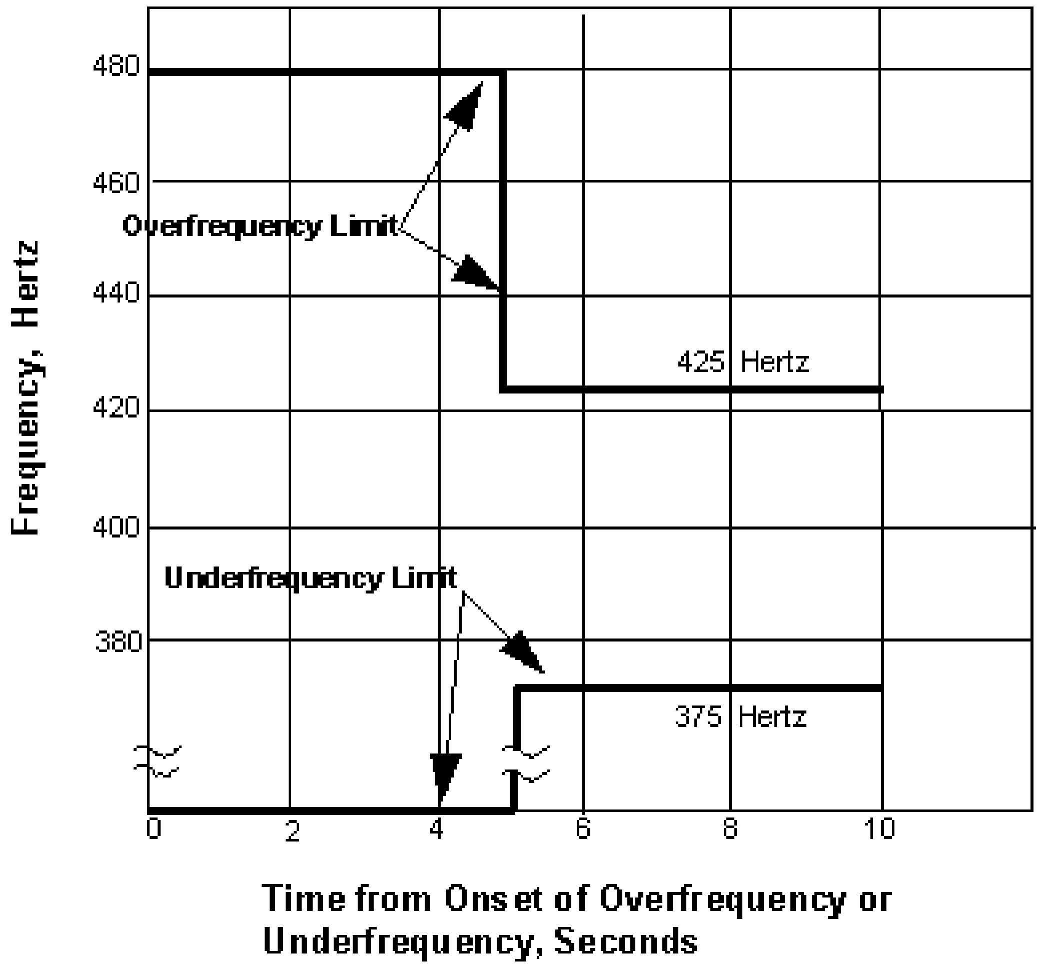

Figure F.5 -- Limits For AC Overfrequency or Underfrequency for Aircraft Power Systems

Lightning can affect electrical equipment by:

(1) a direct strike on the secondary system,

(2) a direct strike on a primary conductor, or

(3) a strike on a nearby object causing an induced voltage in an overhead line by the magnetic field produced.

A model of a voltage transient on a 120 V AC system is waveform which rises to a peak in 500 ns, and then decays in a sinusoidal waveform at a frequency of 100 kHz. DOD-STD-1399 (NAVY), Section 300 gives a rise time of 1.5 s.

F.2.2 Load Switching Transients

F.2.2.1 Power Systems

Switching transients tend to have lower frequencies than the “spikes,” which are of primary concern here. Their levels, at least in the case of restrike-fast switching operations, are generally less than twice normal voltage.

F.2.2.2 Electromechanical Switching

Switching operations involving restrikes, such as those produced by air contactors or switches, can produce voltage escalations reaching several times the system voltage. The worst case is generally found on the load side of the switch. Therefore, it usually involves only the device being switched, and the prime responsibility rests with the end user. However, transients can also affect the line side of the switch. They can be reflected back onto the line and be passed on to other equipment, possible damaging it.

F.2.2.3 Low/High Inductive Sources

Fast rise time voltage transients can cause secondary effects due to inductance in the circuit. This secondary voltage transient is described by the relationship:

$$V(t) \quad = \quad \frac{di}{dt} \quad L$$

Where L is inductance in henries and

$$\frac{di}{di}$$

is time rate change of current.

Induced voltages have been recognized for a long time, but because of their short durations, were not a problem until the introduction of semiconductors. Many power semiconductors are relatively immune to most transients. However, small geometry semiconductors have been damaged with transient voltages of only 25 ns duration.

The waveform of an induced voltage is usually oscillatory in nature. This is because the switch gap alternately sparks over and extinguishes itself. This following sequence occurs: (1) The switch opens and interrupts the line current. (2) The current in the inductor needs to dissipate so it charges the capacitance in the line and interwinding capacitance of the inductor. (3) This raises the voltage until it reaches the spark-over voltage of the switch. (4) At this point the contacts spark over, and the current is dissipated to the load. (5) However, the spark-over occurs very rapidly. When it extinguishes itself it effectively opens the switch, which is a repeatof step (1). The entire process then repeats itself until there is insufficient stored energy left in the inductor to cause the spark-over. The stored energy in the coil is expressed by the following equation:

$$E = \underline{\mathbf{1}}\ LI^{2}2$$

Where:

E = energy in joules

L = inductance in henries

I = current through the inductor in amperes

The maximum inductive switching transient for shipboard 110 volts AC systems is defined by DOD-STD-1399 (NAVY), Section 300, as a peak voltage of 2,500 volts and a waveform as shown in Figure F.6.

This waveform has been adopted as the worst case switching transient which would be generated by a large inductive source. An example of such a worst case transient generator could be an elevator motor on an aircraft carrier.

F.2.2.4 Electromagnetic Pulse (EMP)

During a high altitude nuclear detonation, gamma rays are released which set high energy electrons into motion. These electrons are subsequently deflected by the electromagnetic belt surrounding the earth and an electromagnetic pulse is created. This deflection can generate a voltage pulse of 50,000 V/m at a point 300 miles from the detonation, with a rise time of approximately 5,000 V/s. This is much more severe than a lightning strike, which has a field density of 3 V/m, 6 miles from point of discharge, and a rest time of 600 V/s (see Table F.2). Because of the large magnitude of the voltage and frequency spectrum of an EMP, there are basically no “off-the-shelf” R-C or L-C filters that can effectively reduce or eliminate such an EMP.

Metal Oxide Semiconductor (MOS) circuits and small area geometry semiconductors are especially vulnerable to the EMPs. Because of this vulnerability, effective suppression techniques and protective devices must be used to protect against EMP.

F.2.2.5 Electrostatic Discharge

Electrostatic Discharge (ESD) is a high voltage, low current pulse. Its rise time is in the range of nanoseconds, compared to microseconds for a lighting or switching transient. The rate of voltage increase is about 2 KV/ns and reaches a maximum of about 35,000 V. New generation microcircuits made under the VHSIC program are especially sensitive to ESD. Some can be damaged by less than 100 V.

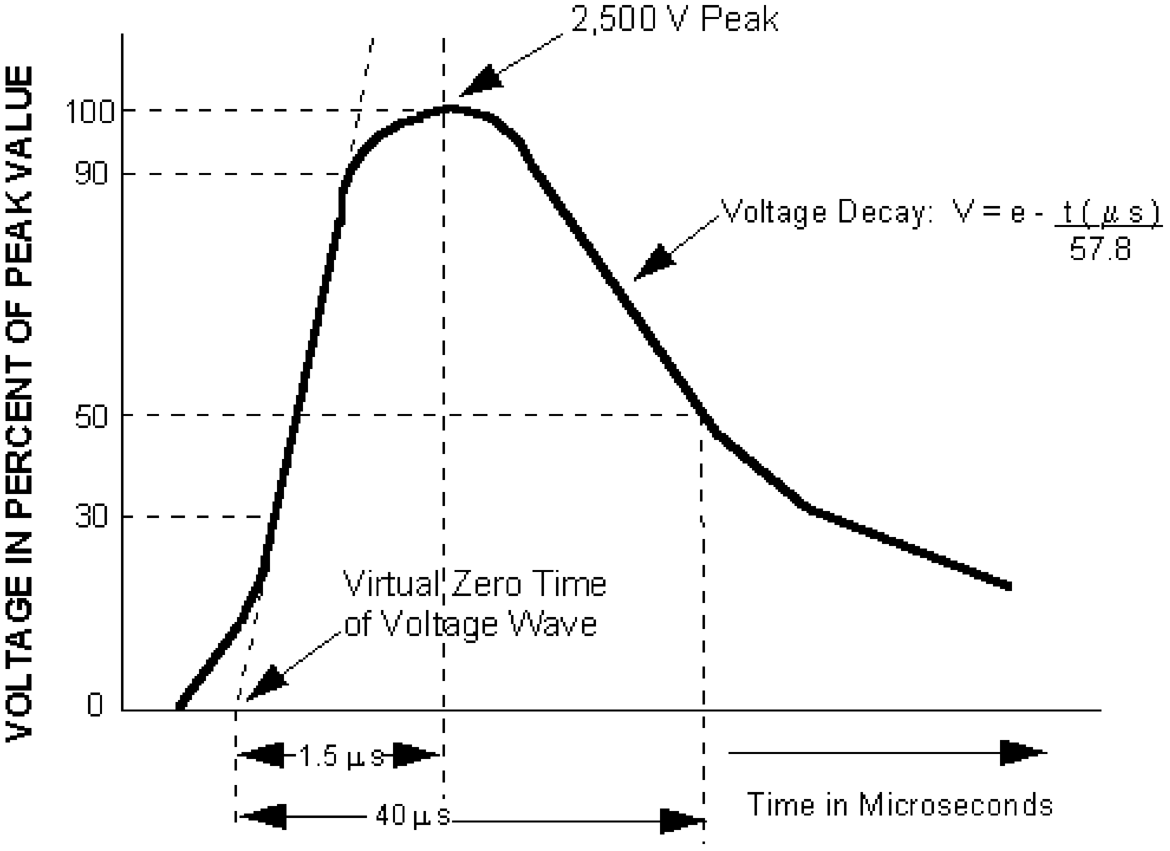

Figure F.6 -- DoD-STD-1399 Wave Form

For additional information on ESD, one should consult MIL-STD-1686 and its accompanying handbook, DOD-HDBK-263. A comparison between EMP, lightning, and static discharge pulses is presented in Table F.2.

F.3 Reducing the Transient Problem

F.3.1 Capacitive Filters

The primary method of suppressing transients is a low pass filter. The simplest form of a filter is a capacitor in parallel with the DC input. This will suppress any transient to which the capacitor presents an impedance lower than the transient source. A capacitor can be an effective filter as long as it:

(1) does not load down the system and create any current in-rush problems (a resistor in series with the capacitor will reduce the in-rush problems but also reduces the effectiveness of the capacitor),

(2) does not have any parasitic inductance which will degrade the high frequency admittance of the device, and

(3) does not degrade with time or ripple current.

Table F.2 -- Comparison of EMP, Lightning and Static Discharge Pulses

Event	**Field Density or Magnitude**	**Rise Time**
EMP (from Nuclear Blast)	50 kv/m @500 km	5 kv/s
Lightning	3 v/m @10 km	600 kv/s
Static Discharge (Human)	2 kv/ns	20 kv at impact

If the transient has high DC components, a capacitor filter can become ineffective. Also, the inductance associated with the filter resistance will reduce its suppression effectiveness.

In addition, transient oscillations (ringing) can develop. When this happens, the capacitor can have the effect of increasing the transient voltage if the transient source is inductive.

Filters are often used in conjunction with transient suppressors. These will be discussed in the next section.

F.3.2 Transient Suppressors

A second method of suppressing voltage spikes is to use a transient suppressor. Basically, this is a device which switches a low impedance load into the circuit when the current or voltage goes over a set limit. The low impedance load then absorbs the excess power, effectively leveling off the spike. To be effective, a transient suppressor must have a fast response time and be capable of handling high energy pulses. It also must be able to clip the transient at a safe voltage level and then dissipate the energy before any damage occurs. Good engineering judgement must be used when selecting a suppressor. Voltage and current spikes are not precisely very predictable, but they obey the laws of probability. Therefore, the statistical distribution of the spikes can be taken into account. Also, the power rating, maximum operating temperature, size, parasitic leakage, and capacitance of the device should all be considered.

F.3.2.1 Basic Requirements of a Transient Suppressor

a. A response time less than the rise time of the transient.

b. A clamping voltage level less than the maximum voltage the equipment can withstand. Also, it should not interfere with the normal operation of the equipment.

c. It should be self-restoring.

d. It should be maintenance free.

To avoid interference with normal equipment operation, zener or varistor clamping voltages should be more than 20 percent higher than the maximum operating voltage of the equipment. On the other hand, the surge protection voltage level (P) should be lower than the equipment withstanding voltage (W).

Although various schemes have been used for transient suppression, such as Zener diodes, avalanche diodes, varistors, RC filters, spark gap arrestors, etc, this discussion will focus on Bipolar Transient Suppressors, avalanche diodes, and metal oxide varistors. Use of circuit breakers, fast fuses, and thermistors is intended to protect against extended overload conditions and these types of devices are not recommended for suppression of fast transients. Section F.3.3 below, is taken from MIL-HDBK-978(NASA).

F.3.3 The Bipolar Transient Voltage Suppressor (TVS)

F.3.3.1 Operation:

The TVS consists of two special construction Zener diodes oriented back-to-back. It is characterized by extremely rapid response time, low series resistance, and high surge voltage handling capacity. These devices are not used as voltage regulators in the usual Zener diode application but as voltage suppression agents. A Zener diode is primarily used as a voltage regulator. Therefore, its selection is concerned with the dynamic slope of breakdown, breakdown voltage minimum and maximum within set limits, and wattage. The transient voltage suppressor is used to suppress voltage surges, wherein the main concern is the breakdown at a set maximum limit and not breakdown before this clamping voltage.

Zener diodes are usually selected for the average power that must be dissipated while regulating. The transient suppressor diodes are selected for the instantaneous power that must be dissipated with less attention being placed on the maximum applied voltage of the transient, when at low current values, as long as the device does not exceed its maximum temperature rating.

Transient suppressors are required to display minimal leakage currents since the clamping voltage is usually set marginally above the maximum operating voltage of the circuit. The Zener diode is not as concerned with leakage current since regulation occurs most often within the avalanche region.

a. Voltage-ampere characteristics. The volt-ampere characteristic for a typical transient voltage suppressor, TVS, given in Figure F.7 shows that the device can conduct current in both directions. Characterized by its two Zener die placed back-to-back, the TVS is useful for bi-directional transient suppression.

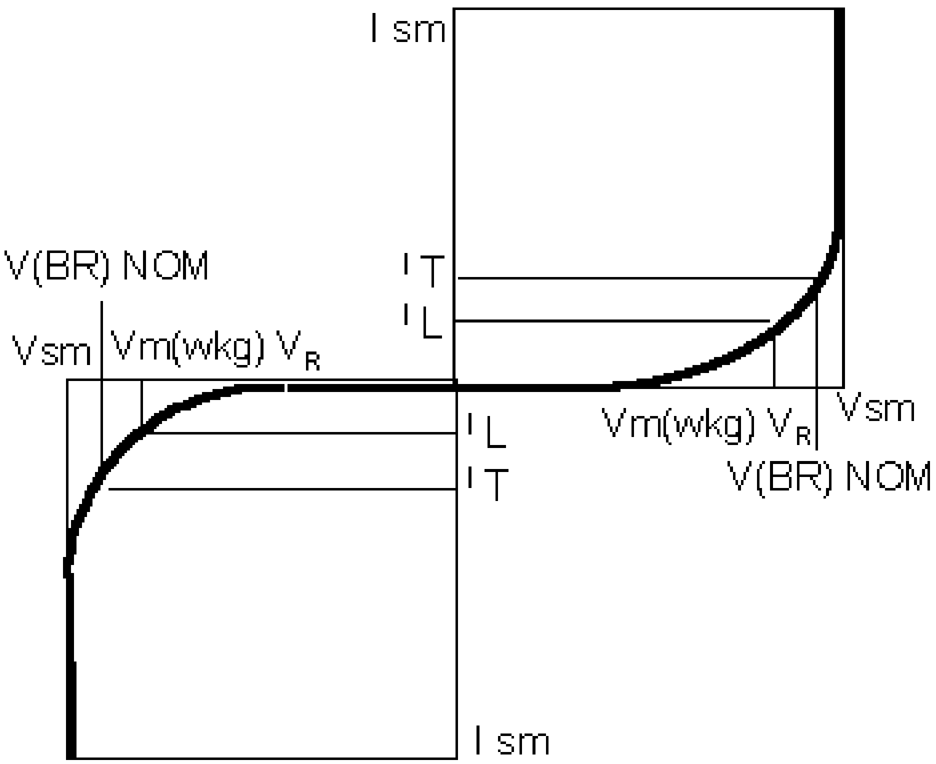

Figure F.7 -- Typical Characteristic Curve for BI-Directional Transient Suppressor.

b. Working peak voltage (VM, WKG) or stand-off voltage (V_R). This parameter is the maximum permissible DC working voltage. It is the highest reverse voltage at which the TVS will be nonconducting.

c. Maximum peak surge voltage (V_{SM}) or maximum clamping voltage (V_{Cmax}). This is the maximum voltage drop across the TVS while subjected to the peak pulse current, usually for 1 ms.

d. Minimum breakdown voltage (BVmin). The breakdown voltage is the reverse voltage at which the TVS conducts. This is the point where the TVS becomes a low impedance path for the transient.

e. Test current (I_T). The current is the zener current at which the nominal breakdown voltage is measured.

f. Maximum leakage current (I_L). This current is the current leakage measured at the maximum DC working voltage (VM or VR).

g. Maximum peak surge current (I_{SM}). This current is the maximum permissible surge current.

F.3.3.2 Physical Construction:

The transient voltage suppressor diode is generally made using two passivated diffused, planar or diffused planar junctions on an epitaxial substrate process die placed back-to-back in a single glass-to-metal or double-slug package. The three basic die processes are passivated diffused, planar, and diffused planar junction on epitaxial substrate, as shown in Figures F.8, F.9 and F.10 respectively.

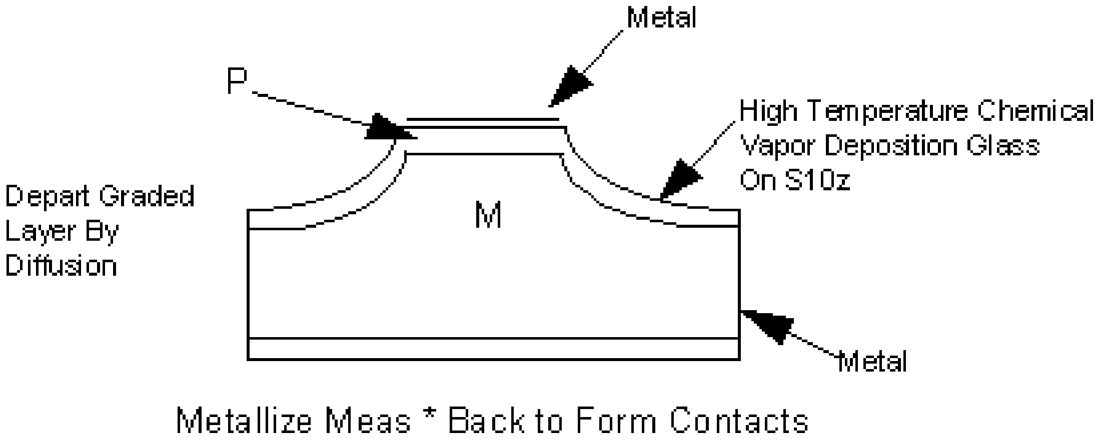

Figure F.8 -- Passivated Diffused Process.

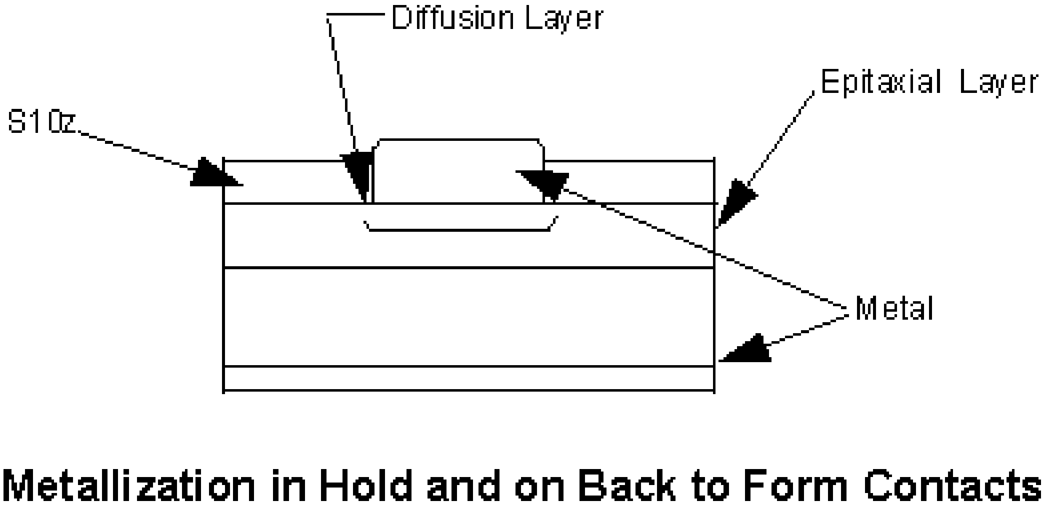

Figure F.9 -- Planar Process.

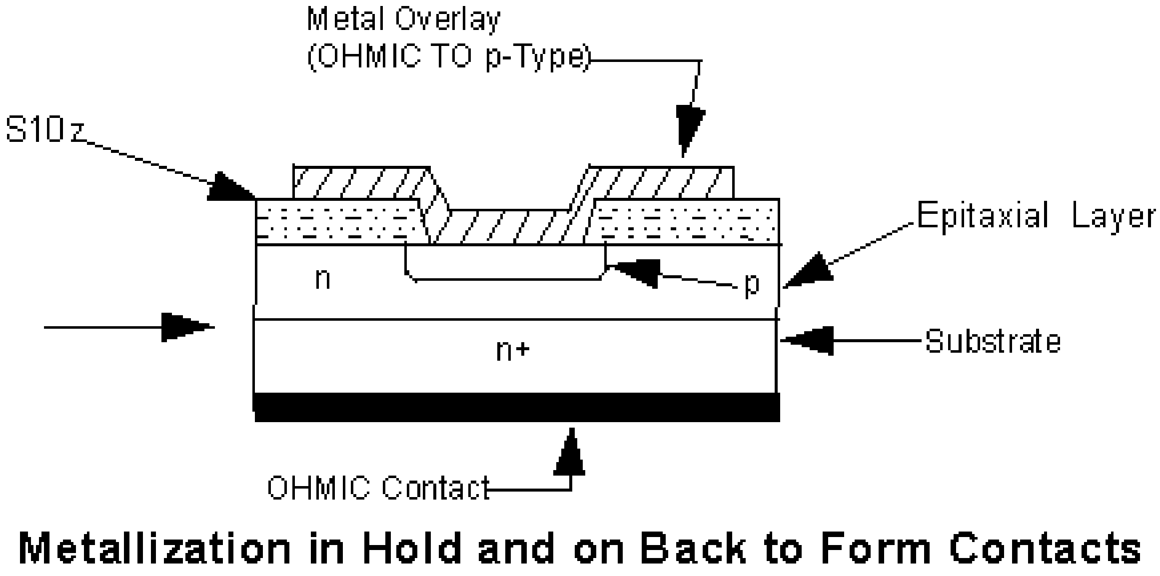

Figure F.10 -- Diffused Planar Junction on Epitaxial Substrate.

Figure F.11 below illustrates the back contact technique used in constructing Transient Voltage Suppressor (TVS) diodes. TVS diodes generally use high temperature alloy back contacts, associated with double-slug construction.

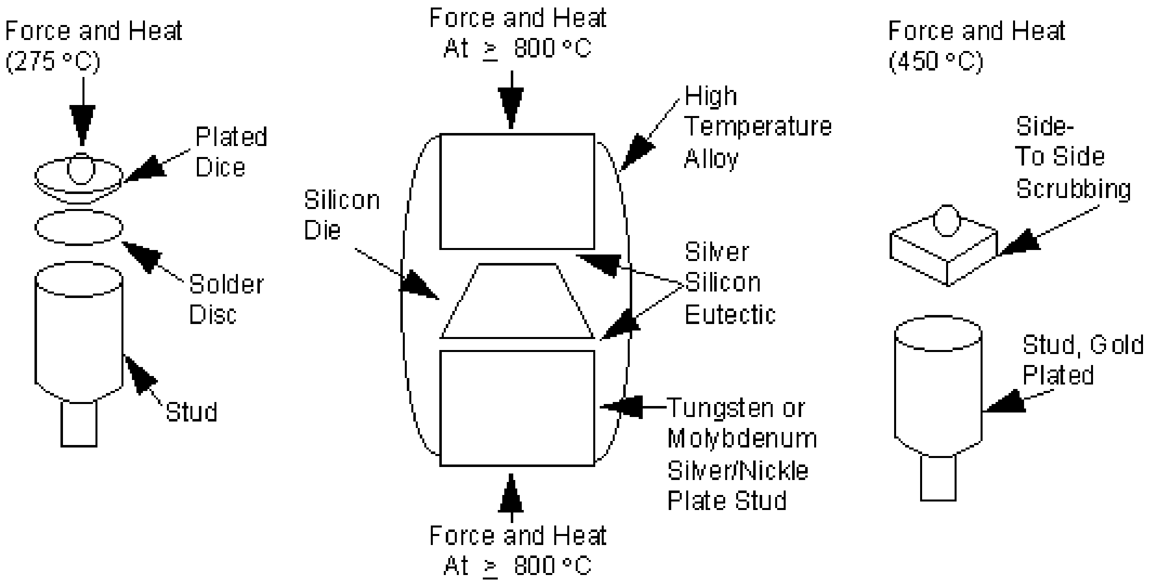

Figure F.11 -- Back Contact Formation Techniques

F.3.3.3 Applications.

When choosing a TVS for a particular application, the following important factors should be considered:

a. The maximum clamping voltage (V_C) should be determined in order to provide adequate protection for a circuit or component. Once V_C has been determined, it will be used to calculate the power for worst case designs for a given application.

b. The TVS selected should display a reverse stand-off voltage (V_R) equal to or greater than the circuit operating voltage (maximum ac or DC peak voltage with tolerances).

c. To select the appropriate TVS one must also determine transient pulse power (P_p). This can be accomplished by using the simple definition; transient pulse power (P_p) equals the peak pulse current (I_{pp}) multiplied by the clamping voltage (V_C).

$$P_p = V_C \text{ x } I_{pp}$$

F.3.3.4 Some Examples

a. ***Microprocessor System TVS Applications.*** The TVS is placed on the signal and input power lines to prevent system failures caused by the effect of switching power supplies, AC power surges and transients, such as electrostatic discharges as illustrated by Figure F.12. A TVS across the signal line to ground will prevent transients from entering the data and control buses. TVSs shunted across the power lines ensure transient-free operating voltage.

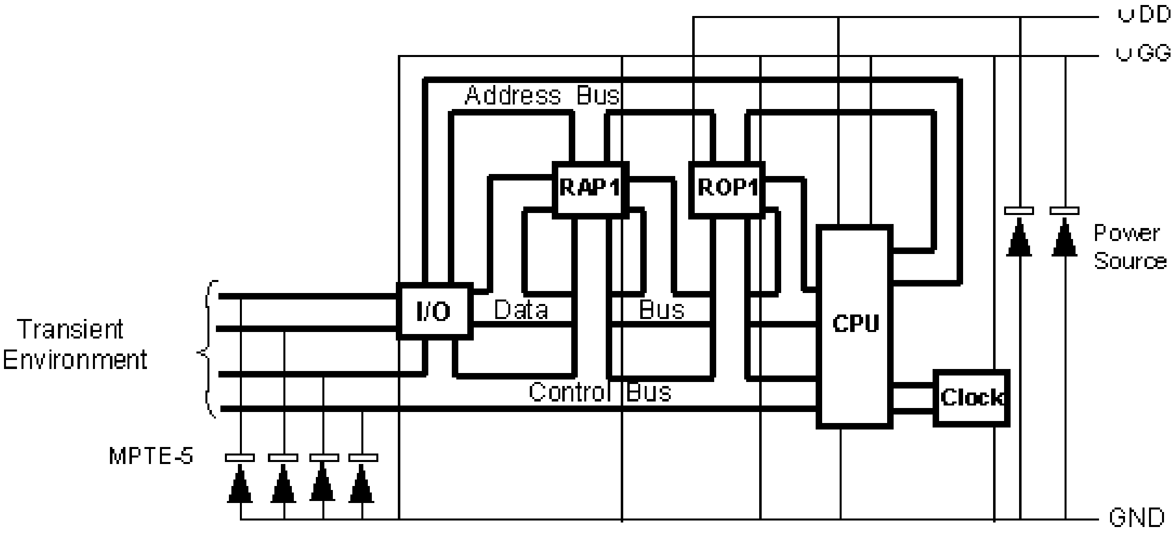

Figure F.12 -- Microprocessor System TVS Application

b. ***DC Line TVS Applications.*** A TVS in the output of a voltage regulator can replace many components used as protection circuits such as the crowbar circuit illustrated by Figure F.13. It may also be used to protect the bypass transistor from voltage spikes across the collector-to-emitter terminals.

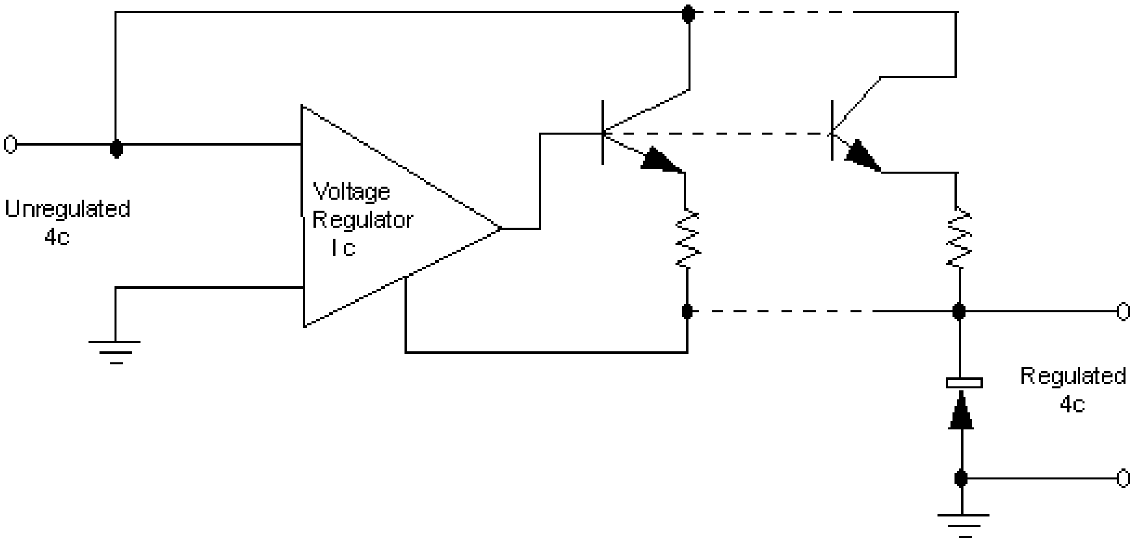

Figure F.13 -- DC Line TVS Application

c. ***Protecting Switching Power Supplies.*** A designer needs to protect against three types of transients: load transients, line transients, and internally generated transients. Because transients have high energy levels they cause improper operation and component failure. The following are typical components that need to be protected in a switching power supply:

(1) High Voltage Switching Transistors
(2) Rectifiers
(3) Output Rectifiers
(4) Control Circuitry

Figure F.14 shows a typical switching power supply with TVS devices used for protection in voltage sensitive areas.

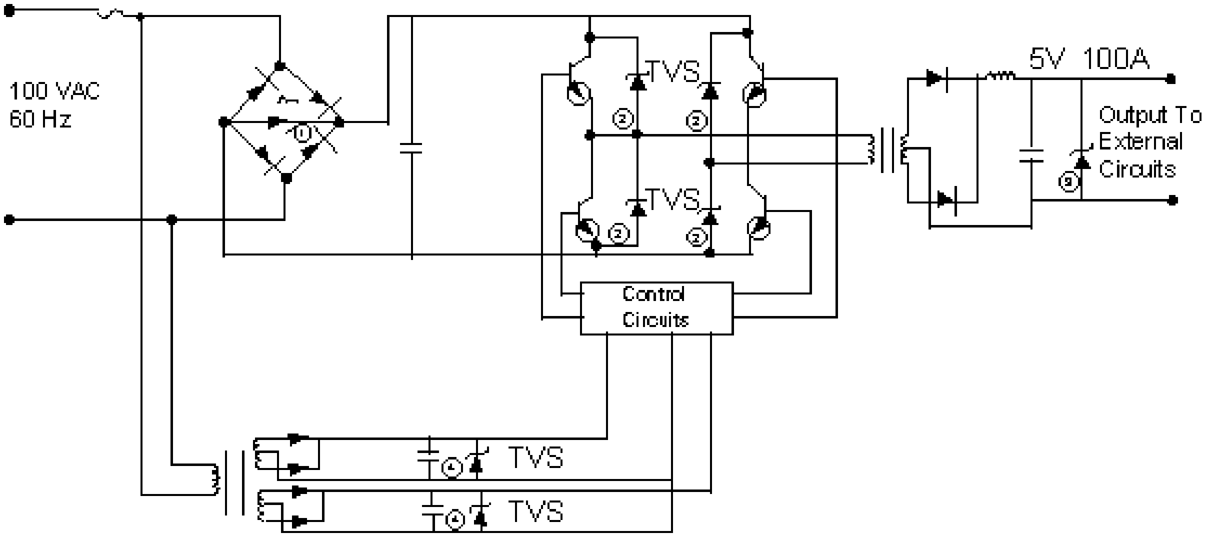

Figure F.14 -- Typical Switching Power Supply

(5) ***Relay and Solenoid TVS Applications*.** The coil inductance of a solenoid or relay can release energy that can damage contacts or drive-transistors. A TVS used as shown in Figure F.15 would provide adequate protection.

The proper TVS can be selected by determining peak pulse power (P_p) and pulse time (t_p). Knowing the values of V_{CC}, L, and, R_L the following equations can be used to determine P_p and t_p.

^{I}O = $^{V}\underline{CC/}\ R_L$

P_P = I_P x V_C

t_l = $^{V}\underline{CC/^{R}L/}\ ^{V}C/^{L}$

t_p = $\underline{t_1}$

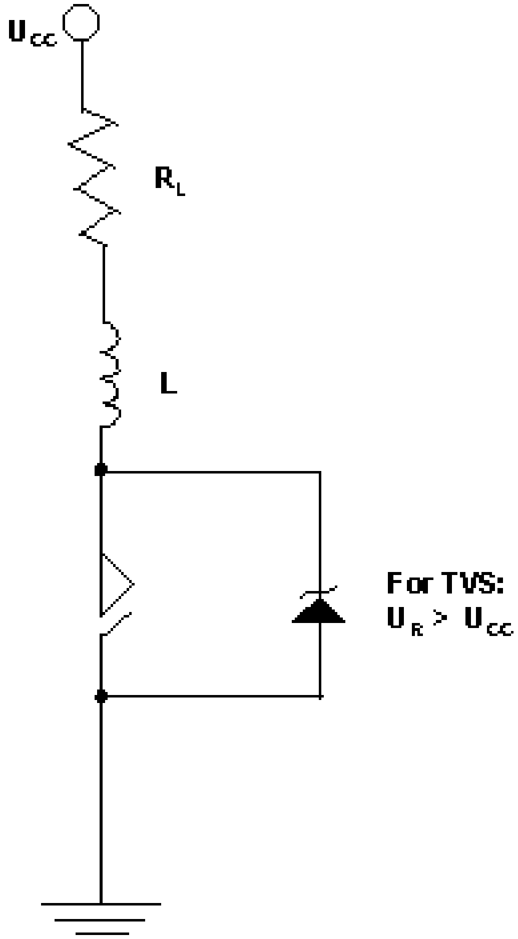

Figure F.15 -- Coil and Contacts, DC.

F.3.3.6 Failure Mechanism and Data.

In extensive tests of transient voltage suppressors, the three most critical parameters were peak pulse power, peak surge voltage and reverse leakage current. Because of its inherent use as a transient suppressor, the TVS must sustain high voltage pulse power. Opens or shorts caused by cracking of the die are main-failure modes if peak reverse power rating is exceeded. Long term life tests have yielded a significant number of failures in these areas. Failure mechanisms of TVSs are similar to those of other diode types.

F.3.4 Avalanche Diode

A second type of semiconductor transient suppressor is the avalanche diode. The avalanche diode was first developed to protect telephone circuits from lightning. This device suppresses surges by limiting the peak voltages through avalanche breakdown. It is especially effective for short duration pulses (i.e., in the order of 10 ms). It can absorb relatively large transients because of its large junction area. It can also quickly dissipate relatively large amounts of heat because it has silver heat sinks which are metallurgically bonded to the silicon chip. The design and structure of this device provides inherently lower impedance compared to zener diodes having the same steady-state voltage ratings.

The clamping speed of the avalanche diode is in the order of microseconds. This gives them the ability to protect very sensitive devices from fast rise time pulses. They are also available in special low inductance configurations.

One disadvantage of avalanche diodes is their large capacitance. This is due to their large junction area. When used on DC or low frequency AC lines, the capacitance will not attenuate or alter the signal. However, in high frequency applications insertion loss occurs. To compensate, a low capacitance diode can be added, as shown in Figure F.16. However, it must have a reverse breakdown voltage greater than that of the suppressor, and must be able to withstand the maximum peak pulse current of the suppressor with the minimum voltage drop across it. The low capacitance diode will also reduce the response time of the suppressor by the very nature of its construction. Under pulse conditions the low capacitance diode, which is essentially a high voltage rectifier, will conduct in the forward conduction mode only. This mode is slower than the avalanche mode of conduction.

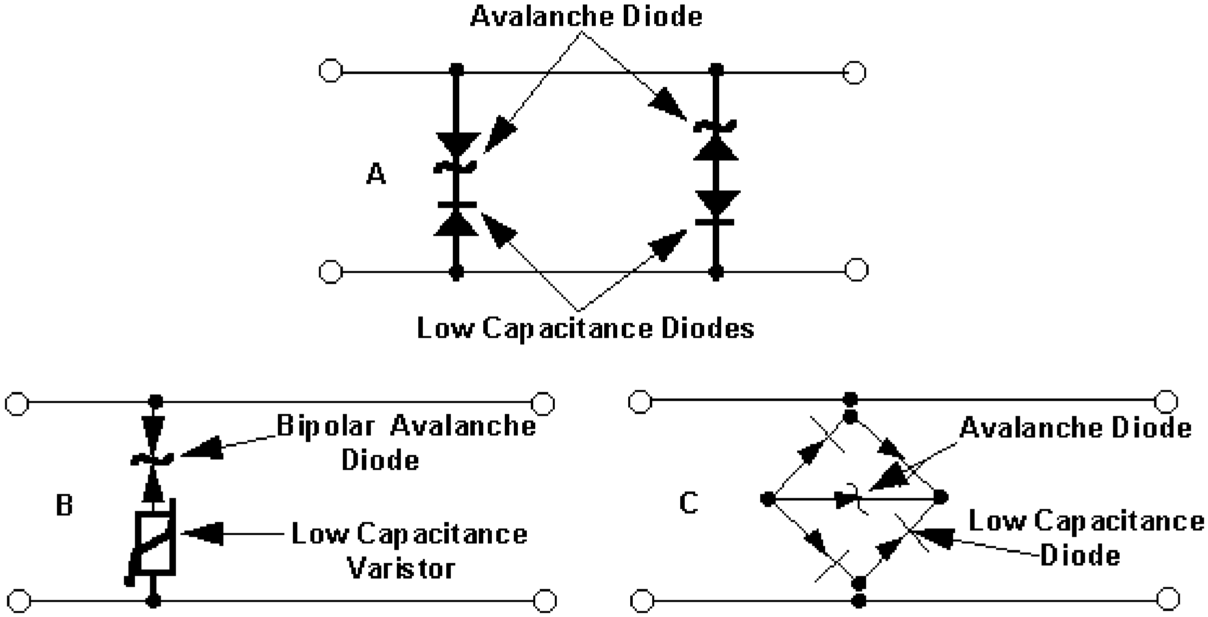

Figure F.16 -- Low Capacitance Protectors

F.3.5 Metal Oxide Varistor

The Metal Oxide Varistors (MOV) is a very nonlinear device. At normal voltages, it has a very high resistance, about 160 kohm. However, when a surge occurs, its resistance decreases by several orders of magnitude. The device is made from a ceramic-like material composed of small granules of zinc oxide suspended in a matrix of bismuth oxide.

At normal voltages, a steady-state current (standby current) flows through the device which is less than 1 mA peak. Once the transient voltage exceeds the normal voltage by about 100 V, the resistance decreases. One disadvantage of the varistor is that a relatively large voltage is needed before suppression begins. This is called a weak knee. The device will also only operate for only a limited number of transient pulses.

Some of the varistor's advantages are voltage-current characteristics comparable to zener diodes, good bipolar suppression capabilities, and high power dissipation ability. It also has a fast response time, which is in the nanosecond range. Figure F.17 illustrates one method for assuming automatic voltage protection of motor starters, thyristors, and diodes.

F.3.6 Suppressor Lead Inductive Effects

Inductive effects can be, and often are, a source of abnormally high peak clamping voltages which can nullify the capability of a transient voltage suppressor. These high clamping voltages can result in failure of vulnerable electronic parts. Therefore, transient voltage suppressors can be rendered ineffective due to inductive effects. To minimize the inductive effect, a zero inductance suppressor element can be used.

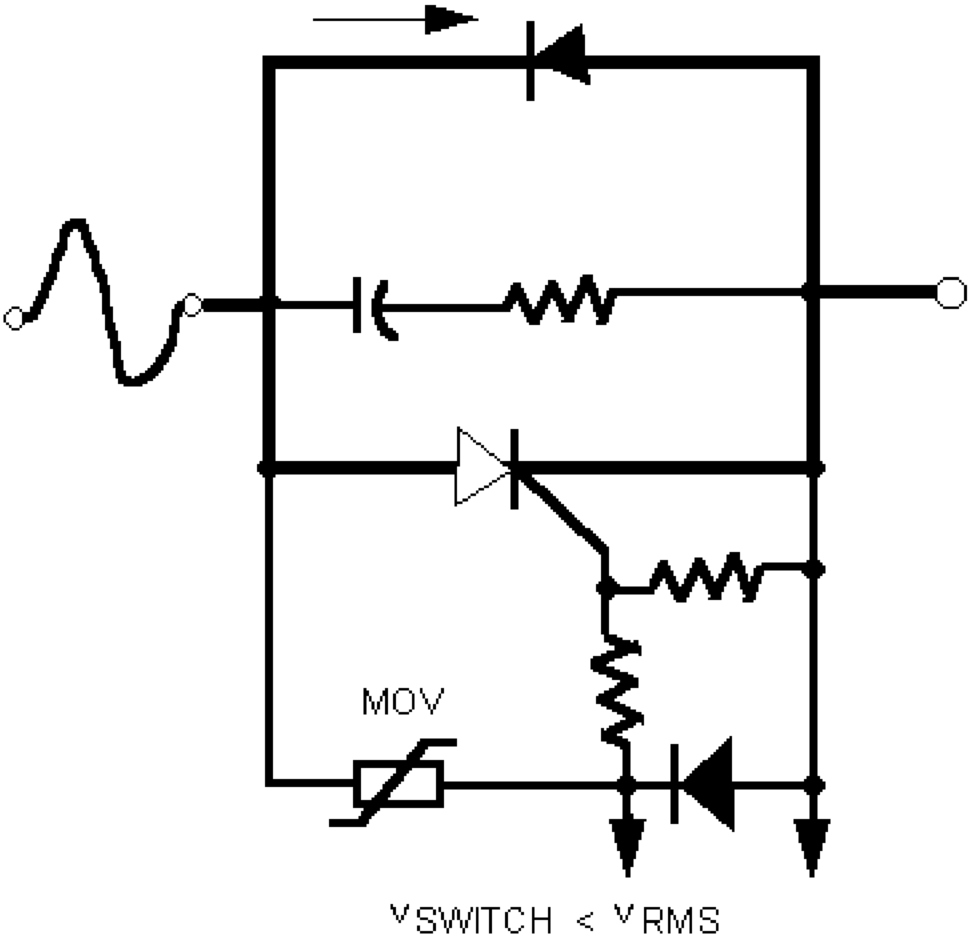

Figure F.17 -- Primary Method for Assuring Automatic Voltage Protection of Motor Starter Thyristors and Diodes

F.3.6.1 Inductive Effects in Component Leads

The voltage developed across an inductor under a voltage step is expressed as:

$$V_L = L \, \underline{di/}\, dt$$

Where: V_L = peak voltage in volts

L = inductance in henries

$\underline{di/}\, dt$ = time rate of change of current

The inductance caused by the lead wires between the suppressor and the circuitry is usually overlooked when designing suppressors into a system. Although the inductance of such lead wires is quite low (about 1 H/m), for fast rise time transients even a few centimeters of lead wire can drastically reduce supressor effectiveness. Inductance causes a voltage overshoot across the leads. For example, if a 20 kV voltage transient occurs, and the total wire length were 10 cm, then the voltage at point A (reference Figure F.18), would be:

$$V = (10 \text{ x } 10^{-2}\text{m})(1 \text{ x } 10^{-6\,H}/\text{m})(4 \text{ x } 10^{9}\ {}^{A}/\text{sec})$$

where:

$$\underline{di/}\ dt = 4 \text{ x } 10^{9}\ (\text{A/sec})$$

Thus:

$$V_A = 400 \text{ volts}$$

Even if this voltage overshoot may not be permanently destructive, it could still cause circuit malfunction. The effect of lead length on peak clamping voltage is shown in Figure F.19 for an ICT-5 type Avalanche (TranZorb) suppressor. This device was designed to protect low voltage logic circuits. It was pulsed at 100, 200, 300, 400 and 500 A with a 1.2 x 50 second waveform. The voltage drop was measured across the 0.030 cm diameter straight wire leads at distances of 0, 1.0 and 2.0 cm from the body of the package. Figure F.18 shows that clamping voltage increases with both pulse current and lead. The increase in clamping voltage with lead length is due to inductive effects.

For fast rise time transients (e.g., ESD which has rise times on the order of 10 ns) lead lengths present a real problem. Therefore, if the protector lead lengths could be reduced to virtually zero, more effective suppression would result.

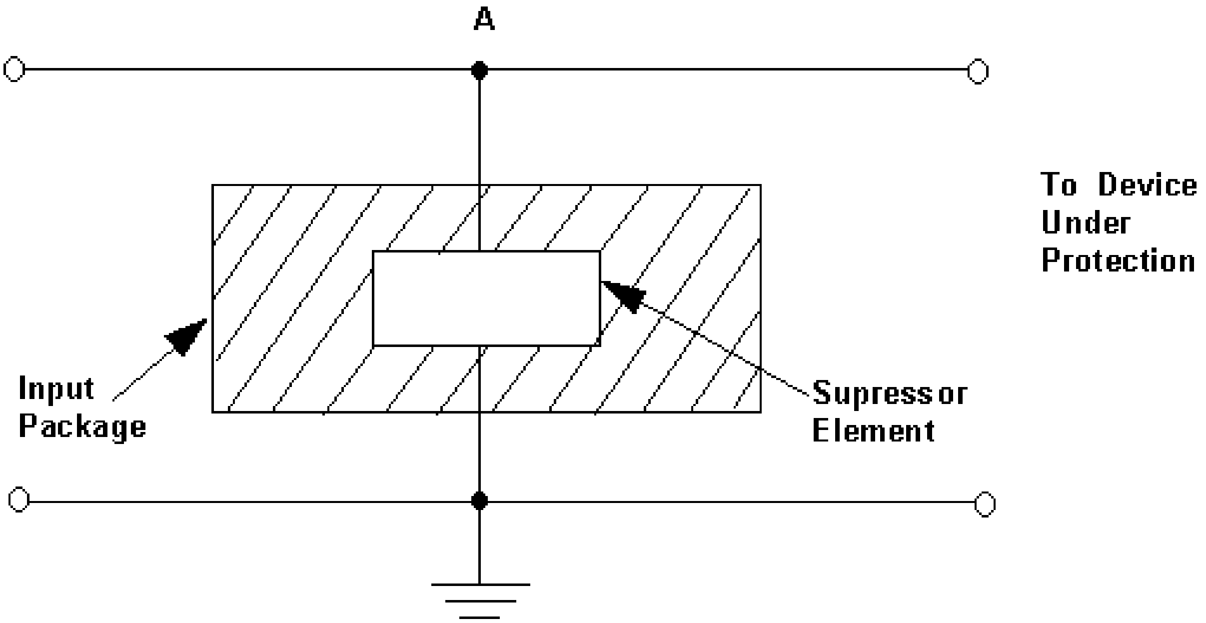

Figure F.18 -- Transient Suppressors With Lead Wire Inductance

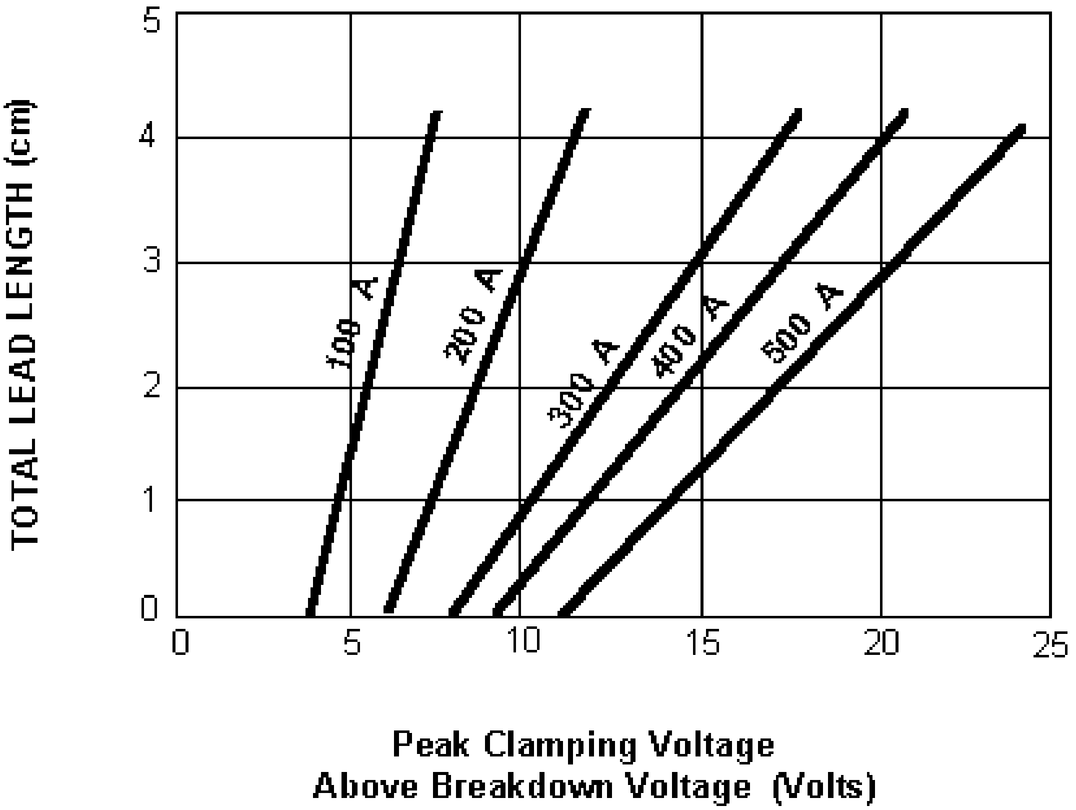

Figure F.19 -- Effects of Lead Length on Clamping Voltage

F.4 Applications

The intent of adding suppression elements is to improve reliability of the equipment, but the opposite effect can occur if the suppressor is not properly chosen. For example, adding a suppressor having marginal capability can be worse than no suppressor at all. Selection of the proper transient suppressor is, for most applications, a five step process:

- Determine the necessary steady-state voltage ratings.
- Establish the transient energy absorbed by the suppressor.
- Calculate the peak transient current through the suppressor.
- Determine any power dissipation requirements.
- Select a device to provide the required voltage limiting characteristics.

Quite often adequate transient protection may not be attainable with only one type of suppressor. For example, high energy transient sources may require the use of spark gaps followed by semiconductor protective devices. A spark gap can divert the high current surge, and a varistor, Zener diode or Avalanche diode can then rapidly clamp the residual voltage.

F.4.1 Avalanche Suppressors

Avalanche operated devices have proven to be effective EMP suppressors. However, each situation must be evaluated on its own particular set of boundary conditions (i.e, circuit operating voltage and frequency, circuit destruct threshold, maximum peak current anticipated, etc). Integrated circuits can be protected by placing an avalanche suppressor across the power line. The suppressor, having a low “on” resistance will reduce unwanted transients while maintaining the circuit voltage level. In case of abnormal transients beyond the maximum current or power ratings of the suppressor, the suppressor will usually fail “short.” This trips the system’s circuit breaker or fuse, but protects the equipment circuitry.

Typical applications of avalanche transient suppressors are as follows:

a. Transient suppressors on power lines prevent IC failures caused by surges, power supply reversals, or transients (see Figure F.20).

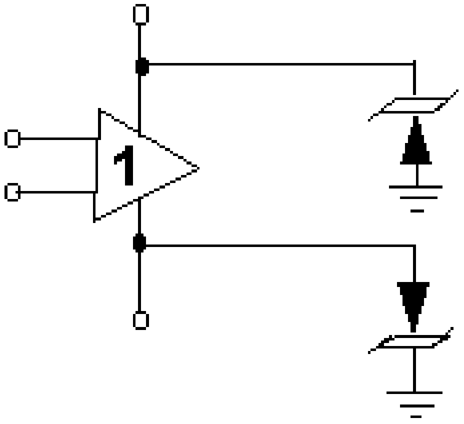

Figure F.20 -- Power Line Transient Suppressor

b. The suppressor protects internal MOSFET devices from transients introduced on the power supply line (see Figure F.21).

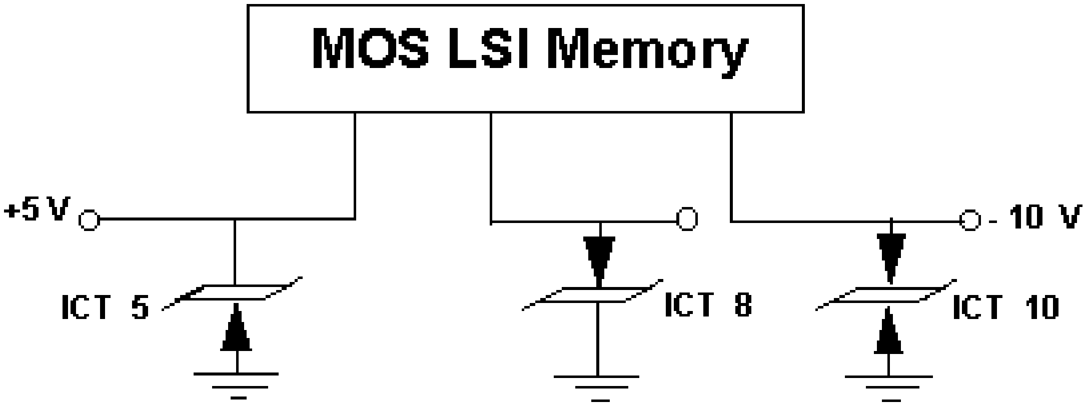

Figure F.21 -- Transient Suppression for MOS Devices

c. A suppressor on the output of an operational amplifier will prevent a voltage transients from being transmitted into the output stage (see Figure F.22). It will also reduce effective capacitance at the output.

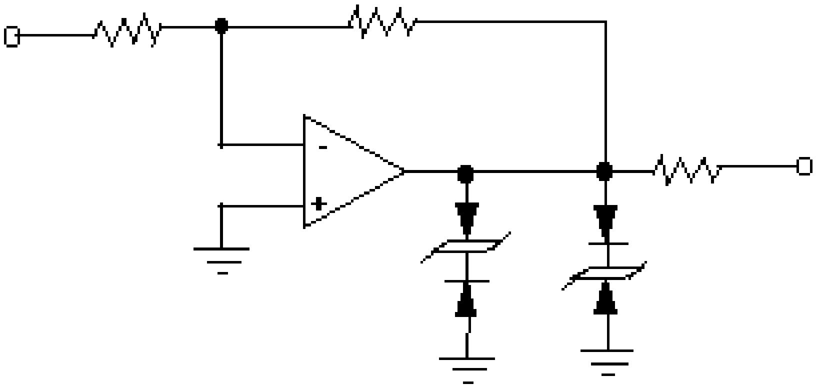

Figure F.22 -- Operational Amplifier Transient Suppression

d. Input stages of operational amplifiers are vulnerable to low energy, high voltage static discharges and EMPs. Limited protection is provided by a clamping diode or a diode input network within the IC substrate (see Figure F.23). The diode, however, must have a breakdown voltage greater than the supply voltage (V_{cc}). Such diodes are limited in current capacity.

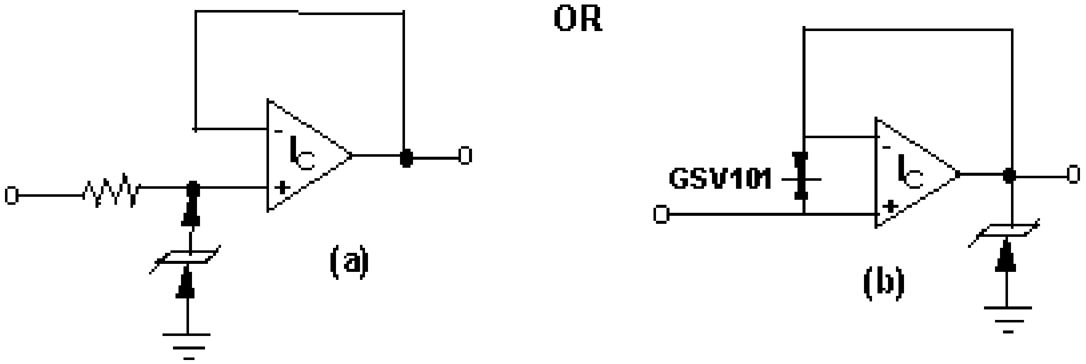

Figure F.23 -- Input Circuit Protection for Operational Amplifiers

e. An avalanche diode across the output terminals of Schottky rectifiers provides protection from load voltage transients. It simultaneously provides effective protection from secondary leakage inductance voltage spikes (see Figure F.24).

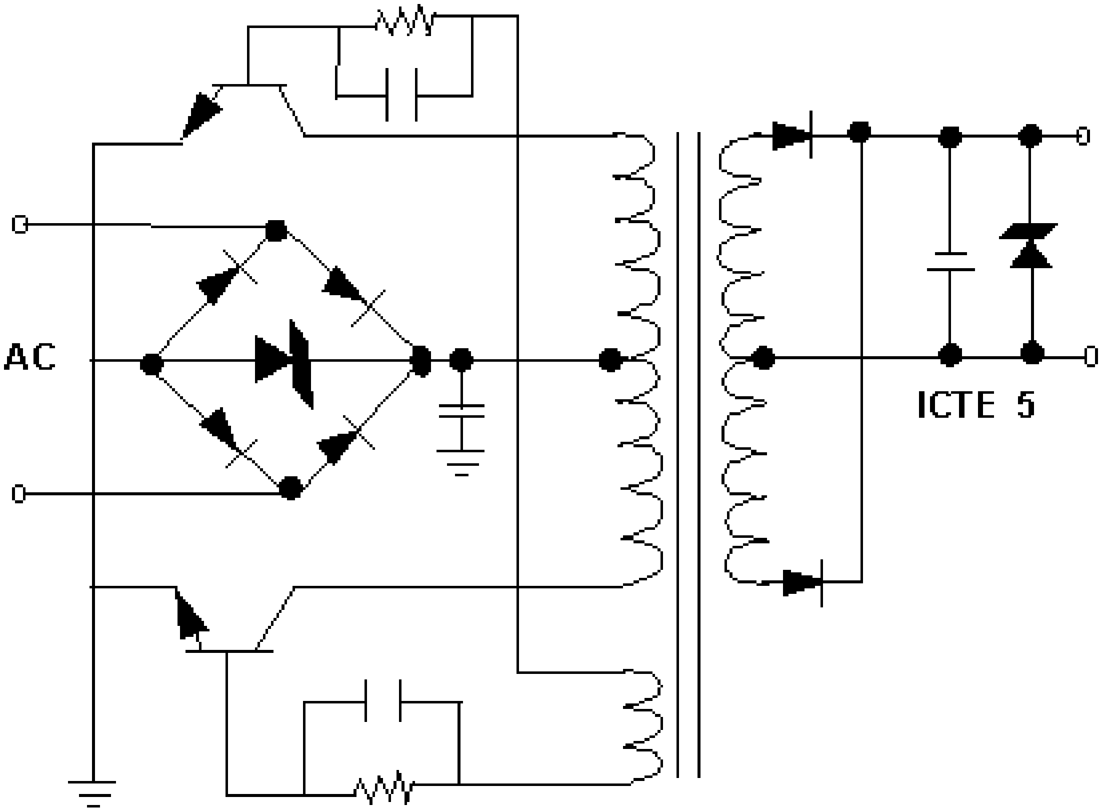

Figure F.24 -- Avalanche Diode Suppression for Schottky Rectifiers

F.4.2 Metal Oxide Varistors (MOVs)

MOVs are a cost effective means of dealing with high, medium, and low level transients. Most MOVs are electrically symmetrical, resembling back-to-back Zener diodes. They are useful in protecting both AC and DC circuits. However, they are not effective in clamping highly repetitive spikes. This is because the MOV's characteristics degrade each time it suppresses a spike. As a consequence, pulse life derating curves identify the operating life of a MOV as a function of peak current, pulse width, and mean number of pulses.

A MOV should not be used in applications were repetitive pulses will occur. For example, assume a high power MOV is capable of suppressing 1,000,000 pulses, 20 ms wide at 50 A peak. Operating at 10 kHz, the MOV can function for only 100 s. By that time the characteristics have deteriorated enough so that rated specifications are no longer guaranteed.

MOVs are recommended for use in circuits where medium to high surge currents are expected on a random basis, and where maximum insulation resistance and minimum discharge voltage are not important. MOVs provide good protection together with small size, low cost, and large energy handling capacity. They are available with clamping voltages between 22 and 1,800 V, peak surge capacities from 250 to 20,000 A, and response times in the order of 50 ns. MOV ratings of energy, power dissipation capability, voltage, and peak current, are temperature dependent. Therefore, it is important to use derating curves when selecting MOVs.

MOVs have some drawbacks for high frequency applications. They can exhibit high shunt capacitance in the range of 10 pf to about .02 f. Most varistors are also slightly inductive.

Table F-3 is a general guide for comparing various types of transient suppressors with ratings on their performance characteristics. The higher the rating number (e.g., 4), the better the device performance characteristics.

Table F.3

Characteristics	**Silicon Avalanche Suppressors**	**Zeners TVS**	**MOVs**
Voltage Capability	3	1	3
Peak Current Capability(non-repetitive)	2	1	2
Leakage Current	4	3	2
Energy Absorption Capability (Repetitive)	4	2	2
Response Time	4	2	2
Operating Temperature	3	2	2
Life	3	2	1
Size	3	4	4
Cost	1	3	3

* Due to low network resistance.

Note: Ratings are based on a scale of one to four; the higher the number the better the rating.

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Section 800 -- Switches

800 Switches

800.1 General Information

Standard switches shall be selected from MIL-STD-1132. Effective and proper selection of switches and associated hardware, requires an awareness of the advantages and disadvantages of different types of switches, their behavior under various environmental conditions, switch construction, the effect of the switch upon the circuit, and the effect of the circuit upon the switch.

800.1.1 Choice of Switch Types and Associated Hardware

The designer should consider the following characteristics and parameters in choosing the most suitable switch design and associated hardware:

a. Application (type of switch)

b. Flexibility of circuitry

c. Type of action

d. Electrical data (contact ratings, etc.)

e. Type of contacts

f. Environmental capabilities such as shock and vibration

g. Mechanical data and safety features

h. Panel layout

I. Quality and reliability requirements

j. Economics (cost/benefit trade offs)

800.1.2 Switch Types

Switches can be grouped into five basic types:

a. Push and sensitive

b. Toggle

c. Rotary

d. Thermostatic

e. Pressure

These types differ from each other in size, cost, actuation, construction, and general mechanical and electrical characteristics.

800.1.3 Switch Selection Factors

Selection factors are noted below:

a. ***Design and Construction***

   (1) Open or enclosed construction

   (2) Sealed (hermetically, environmentally resilient, dust-tight, water-tight, explosion-proof)

   (3) Mounting (bushing, multihole, mounting bracket, mounting plate)

   (4) Illuminated or nonilluminated

b. ***Operating characteristics***

   (1) Actuation -- pushbutton, toggle, rotary, sensing

   (2) Switching action -- momentary action, maintained action, alternate action, snap action

c. ***Contacts***

   (1) Type of contacts and contact arrangement

   (2) Contact ratings -- resistive, inductive, lamp, motor, capacitive, and frequency

   (3) Contact bounce time

   (4) Contact resistance

   (5) Make-before-break, break-before-make, shorting or nonshorting contact

d. ***Environmental Considerations***

   (1) Temperature range

   (2) Moisture

   (3) Altitude

    (4) Shock and vibration
    (5) Acceleration
    (6) Sand and dust
    (7) Explosion

e. ***Insulation Requirements***

    (1) Insulation resistance
    (2) Breakdown voltage

f. ***Switching speed***

    (1) Actuation speed

g. ***Life***

    (1) Mechanical
    (2) Electrical at elevated temperature

h. ***Terminals***

    (1) Solder
    (2) Screw
    (3) Wire
    (4) Plug-in termination
    (5) Integrated wire termination
    (6) Printed-circuit board terminations

800.2 Application Considerations

Application considerations in the selection of switches include the following.

800.2.1 Enclosures

Many types of enclosures are used to protect switches from varying external conditions, particularly high humidity and dirt. Switches may be classified based on the degree of protection offered by the enclosure. Such classifications include the following: open, sealed, enclosed, environmentally (resilient), and hermetically sealed. With the open construction switch, no effort is made to protect the switch or its parts from atmospheric conditions. The enclosed switch is one in which the contacts are enclosed in a case made of plastic or metal and plastic. The environmentally (resilient) sealed switch contains a completely sealed case where any portion of the seal is resilient material such as a gasket or a seal. The hermetically sealed switch is made air tight by a sealing process which involves fusing or soldering and does not use gaskets. The hermetically sealed enclosure offers the greatest protection because it insulates against such elements as moisture, harmful gases, and dirt. It also eliminates the increased arcing caused by low atmospheric pressures at high altitudes.

800.2.2 Contacts

The switch electrical contacts can be classified by function, current carrying capacity, and application. The contact arrangements vary in complexity from a simple make or break, through make-before-break, break-before-make, make-make, break-break, etc.; from a single-throw to multiple-throw, single pole to multipole; and various combinations of these features.

800.2.2.1 Contact Ratings

Contacts are usually given multiple ratings dependent on the type of load being switched. These ratings consist of resistive, capacitive, lamp, motor, or inductive loads. Most switches are given the resistive load rating and in most instances at least one additional rating mentioned above. Extra care should be used in selecting switches for motor, inductive, or lamp loads. Also, see section 800.3 on derating.

800.2.2.2 Contact Operate and Bounce Times

In many instances, critical operate and bounce times of the contact are important. Operate time in a double-throw switch is defined as the time it takes the moving contact to separate from the normally closed contact, travel to the normally open contact and make the circuit, not including bounce time. Bounce time is the interval between first make of the contact until any uncontrolled making and breaking of the contact ceases. In many electronic circuits, a millisecond is a long time and operate and bounce times become critical parameters.

800.2.2.3 Contact Resistance

Contact resistance is the resistance between two mating closed electrical contacts measured at their external terminals. Contact resistance can be used to measure voltage drop and power dissipation across the contacts. Contact resistance includes the resistance of the contact material, oxide or other film on the surface of the contacts, and the resistance of the elements on which the contacts are mounted (e.g., springs, mounting, and the external terminals and their connections).

800.2.3 Low-Level (Dry Circuit) Applications

Dry circuit applications require switch contact resistance ratings based on testing, using an open circuit voltage of 30 millivolts maximum and a test current of 10 milliamperes maximum (e.g., Method 311 of MIL-STD-202). In order to achieve low-level load capability, suppliers often use contact materials such as gold, platinum, palladium (or their alloys) to minimize formation of insulating films on the contacts. They also design switch contacts so that they wipe across each other to remove such films. Other considerations are: to provide internal designs which do not allow rubbing of insulated parts against metal that generates dust particles internally; and to adequately seal the switch contacts from external dust and foreign matter since foreign particles being deposited on the switch contacts increases contact resistance. Proper test and performance requirements before and after life tests should be the basis for selection of these switches.

800.2.4 Insulation Resistance

Insulation resistance is important in high impedance circuits. Low insulation resistance in a high voltage circuit can result in excessive dissipation within the dielectric leading to failure. For applications where arc-over is a problem, switches should be selected which have a high insulation resistance (1,000 megohms or more and 5 megohms or more as measured immediately after the moisture resistance test). Properly rated insulating materials, furthermore, will not form a conducting surface film buildup after repeated arcs on making and breaking of contacts.

800.2.5 Life Operations for Total Life

A careful analysis of the required life of the switch or total number of operations should be made. In some equipment applications, the operational life of the switch can be comparatively short.

800.2.6 Environmental Considerations

800.2.6.1 Temperature

a. Variations in temperature shall be considered, as moisture condensation within the switch could develop. In choosing a switch for a wide range of temperature, the entire temperature range must be considered rather than only one extreme.

b. Exposure to low temperature may cause certain materials of a switch to contract, causing case cracking or opening. Such failure could result in moisture or other foreign matter entering the switch causing short circuit, voltage breakdown, or corona.

c. Chemical action of switch materials are accelerated by high temperatures. Insulation resistance between the switch contacts and ground decreases as the temperature increases. High temperature can also affect the insulation from the standpoint of voltage breakdown due to a change in dielectric strength, as well as accelerate contact and switching mechanism corrosion.

800.2.6.2 Moisture

Moisture in the dielectric will decrease the dielectric strength, life, and insulation resistance and could cause corrosion by increasing the galvanic action between dissimilar metals in the switch. Switches which operate in high humidities shall be hermetically sealed, or if this is not applicable, the use of boots, “O” rings, or diaphragms placed over switch openings, is recommended to decrease moisture entry.

800.2.6.3 Altitude

With a decrease of atmospheric pressure, the spacings required to prevent flashover increase substantially. Small switches, because of their very close contact spacing, are particularly susceptible to malfunction at high altitudes. Contact life decreases substantially with continued arc-over.

800.2.6.4 Shock and Vibration

Switches should be selected that will operate under expected shock and vibration. Those with contact chatter limitations can be used in low frequency and shock vibrations. High frequency vibration will determine the effects of fatigue and resonance on the mechanical construction of the switch contact elements. Contact bounce due to shock or vibration causes arcing which shortens contact life and could generate electrical noise.

800.2.6.5 Acceleration

Some switches are sensitive to acceleration forces arising from use in high speed vehicles or aircraft. Failures are usually due to internal construction which allows normally closed contacts to open and normally open contacts to close under acceleration conditions.

800.2.6.6 Sand and Dust

A combination of dust and small amounts of moisture will increase the possibility of voltage breakdown of the insulation between closely spaced terminals. Where low insulation resistance or high leakage currents can cause circuit malfunction, the switch should be capable of passing sand and dust test requirements.

800.2.6.7 Explosion

Explosion resistance requires that switches operate in a volatile atmosphere without causing explosion. Wherever possible, switches to be used in an explosive atmosphere shall be sealed.

800.2.7 Precautions

a. Switch contacts shall be operated in parallel for redundancy only and never to “increase the current rating.”

b. Switch applications in digital circuits must be carefully reviewed to assure that contact bounce or chatter will not be interpreted as pulses which will produce logic errors.

c. Switches are subject to contact chatter in high shock and vibration environments, and these environments may dictate the use of solid state devices. The mounting of switches shall be designed to minimize vibration and shock amplification or to provide necessary isolation.

800.3 Derating

Switches shall be derated according to Table 800-I.

Table 800-I -- Derating Requirements

Derating Parameter	% of Max. Rated Value of Resistive Load
Contact Current (Continuour)	60 -- Capacitive load 60 -- Resistive load 40 -- Inductive load 20 – Motor 10 -- Filament (Lamp)
Vibration	75 (including "Q" of mounting)
Contact Current surge)	80
Maximum Derated Ambient Temperature	Limit to 20ºC – 25ºC below the specified maximum

800.4 Quality Level

Only ER level "P" or higher shall be used.

800.5 Use Applications of Switches

The principal applications of various types of switches are provided in Table 800-II.

Table 800-II -- Switch Applications

Switch Type	MIL-SPECNo.	Application
Switch, Push-Button Illuminated	Mil-S-22885	Used as panel displays and switching devices in ac and DC applications. Panel displays include various combinations of colors and legends.
Switches and Switch Assemblies, Sensitive and Push (Snap Action)	MIL-S-8805	Used in ac and DC applications, where predetermined small and accurately controlled characteristics are required. Various means of actuation by toggle levers, push-buttons, cams, and other light pressure devices. These switches have snap-action which eliminates teasing.
Switches, Multi-Station, Push- Button (Illuminated and Nonilluminated)	MIL-S-23417	Used as panel displays and switching devices in ac and DC applications.

Switches, Pressure	MIL-S-9395	Used primarly to detect changes in pressure, liquid and gas applications.
Switches, Rotary	MIL-S-3786	Used primarily for low power, alternating current (AC) or direct current (DC) switching applications(capable of making and breaking a resistive load of 2 amperes or less). Includes both manually and solenoid actuated switches.
Switches, Rotary Selector Power	MIL-S-6807	Used in power circuits capable of making, arraying, and breaking electrical loads of 10 amperes or less.
Switches, Rotary(Printed Circuit), (Thumbwheel, Inline, and Push-Button)	MIL-S-22710	Used primarily for low power AC or DC switching applications. Thumbwheel switches provides a numerical or other legend readout tied to a particular switch position. Also provided for is logic circuitry for computer operation.
Switches, Thermostatic(Metallic and Bimetallic)	MIL-S-24236	Used primarily in ac and DC applications where temperature protection or accurate temperature control or an enclosure is required.
Switches, Thermostatic(Volative Liquid), Hermetically Sealed	MIL-S-28827	Used primarily in ac and DC applications that require rapid temperature response.
Switches, Toggle Environmentally Sealed	MIL-S-3950	Used where simple make-and-break actions are required and are suitable for use on AC and DC circuits.
Switches, Toggle, Positive Break	MIL-S-8834	Used in AC and DC circuits where a positive make-and-break action is required. Positive break actuation causes minimum contact “tease”.
Switches, Air and Liquid Flow	MIL-S-28788	
Boots, Dust and Water Seal	MIL-B-5423	Used on toggle, push-button and rotary switches to protect the switch actuating mechanism from sand, dust,

		water, and other contaminants, and to seal the panel on which the switches are mounted.
Switches, Reed	MIL-S-55433*	
Switches, Snap Action	MIL-S-15291*	
Guards	MIL-G-7703*	

*Standard switches are to be established for these specifications.

Next Section