CHAPTER 3.2

DERATING FACTORS AND APPLICATION GUIDELINES

W. R. Lehmann, Kurt E. Gonzenbach, Neil V. Owen,
Edwin W. Kimball

INTRODUCTION

The following derating guidelines were developed and adopted for use in designing equipment manufactured by Martin Marietta Orlando Aerospace, and it must be recognized that they may be too strict for use by designers of equipment for other markets, such as nonspace or nonmilitary applications. It is also recognized that to achieve higher projected reliability, customers for certain specialized equipment may impose derating factors even more severe than those given here. Nevertheless, the principles underlying the idea of derating are useful in all applications.

Derating is the reduction of electrical, thermal, mechanical, and other environmental stresses on a part to decrease the degradation rate and prolong its expected life. Through derating, the margin of safety between the operating stress level and the permissible stress level for the part is increased, providing added protection from system overstresses unforeseen during design.

The criteria listed in this section indicate maximum application stress values for design. Since safety margins of a given part at failure threshold and under time-dependent stresses are based on statistical probabilities, parts should be derated to the maximum extent possible consistent with good design practice.

When derating, the part environmental capabilities defined by specification should be weighed against the actual environmental and operating conditions of the application. Derating factors should be applied so as not to exceed the maximum recommended stresses.

For derating purposes the *allowable application stress* is defined as the *maximum allowable percentage of the specified part rating at the application environmental and operating condition*. Note that ambient conditions specified by the customer usually do not include temperature rise within a system that results from power dissipation. Thus, a thermal analysis must be performed early in the development phase to be used in the derating process.

Experience has shown that electronic part derating is the single most significant contributor to high reliability. Going from no derating to 50 percent derating can conservatively raise circuit mean time between failure by a factor of two to five times. In addition, important cost benefits can be achieved by optimized electronic part derating. Powerful analytical methodology is presently available for performing trade-off studies aimed at determining the amount of derating most desirable for various product lines.

RESISTOR DERATING AND APPLICATION GUIDELINES

Resistor Types

Variable and fixed resistors are of three types: composition, film, or wire-wound (see Sec. 5). The composition type is made of a mixture of resistive materials and a binder molded to lead wires. The film type is composed of a resistive film deposited on, or inside, an insulating cylinder or filament. The wire-wound type consists of a resistance wire wound on an appropriate structural form.

General Applications. For ordinary military uses *established-reliability* (ER) part types are contractually required as preferred parts.

1. MIL-R-39005, RBR (fixed, wire-wound, accurate). Higher stability than any composition or film resistors, where high-frequency performance is not critical. Extremely close tolerances of ±1 to ±0.01 percent, with end-of-life tolerance shifts of ±0.02 percent. Operation is satisfactory from dc to 50 kHz. Relatively high cost and large size.

2. MIL-R-39007, RWR (fixed, wire-wound power type). Select for large power dissipation and where high-frequency performance is relatively unimportant. Generally satisfactory for use at frequencies up to 20 kHz, but the reactive characteristics are uncontrolled except for available "noninductive"-type windings at reduced resistance ranges. Wattage and working voltage must not be exceeded. Power derating begins at 25°C ambient. Bodies get very hot at rated power and may affect adjacent components or materials. Also the silicon coating used on some of the RWR resistors can be dissolved by some cleaning solvents. Regardless of purchase tolerance, the design will meet an end-of-life tolerance of ±1 percent.

3. MIL-R-39008, RCR (fixed, composition-insulated). Select for general-purpose resistor applications where initial tolerance need be no closer than ±8 percent and long-term stability no better than ±20 percent at room temperature under fully rated operating conditions. RF characteristics in resistance values higher than about 500 Ω are unpredictable. These resistors generate thermal "noise" that would be objectionable in low-level circuits. They are generally capacitive, are very reliable in catastrophic failure modes, and are also very inexpensive.

4. MIL-R-39009, RER (fixed, wire-wound power type, chassis mounted). Relatively large power dissipation in a given unit size. RF performance is limited. Minimum chassis area for heat dissipation is stated in the specifications and is essential to reach rated wattage. Not as good as RWRs in low-duty-cycle pulsed operation where peaks exceed steady-state rating. End-of-life tolerance of ±1.5 percent.

5. MIL-R-39015, RTR (variable, wire-wound, lead-screw-actuated trimmer). Use for adjusting circuit variables. Requires special consideration in severe environments. These resistors are not hermetically sealed and are susceptible to degraded performance because of ingestion of soldering flux, cleaning solvents, and conformal coating during manufacturing. Should be used with fixed resistors, if possible, in a circuit designed to reduce sensitivity to movable contact shift. Use larger sizes if possible.

6. MIL-R-39017, RLR (fixed, metal film). These resistors (mostly thick film) have semiprecision characteristics and small size. These size and wattage ratings are comparable to those of MIL-R-39008, and stability is between that of MIL-R-39008 and MIL-R-55182. Design-parameter tolerances are looser than those of MIL-R-55182, but good stability makes them desirable in most electronic circuits. RF characteristics in values above 500 Ω are much superior to composition types. Initial tolerances are ±2 percent and ±1 percent, with an end-of-life tolerance of ±5 percent.

7. MIL-R-39035, RJR (variable, non-wire-wound, lead-screw-actuated trimmer). Use for adjusting circuit variables. Use of potentiometers in severe environments requires special consideration. These resistors are not hermetically sealed and are susceptible to degraded performance because of ingestion of soldering flux, cleaning solvents, and conformal coating during equipment manufacturing. Should be used with fixed resistors, if possible, in a circuit designed to reduce sensitivity to movable contact shift.

8. MIL-R-55182, RNR/RNC (fixed, film, high stability). RNR/RNC resistors are available in hermetic and nonhermetic cases. For most applications, where a moderate degree of protection from the environments is provided, the nonhermetic parts have been proven reliable. Use in circuits requiring higher stability than provided by composition resistors or thick-film, insulated resistors and where high-frequency requirements are significant. These thin-film resistors provide the best high-frequency characteristics available unless special shapes are used. Metal films are characterized by low temperature coefficient and are usable for ambient temperatures of 125°C or higher with small degradation. End-of-life tolerance is ±2 percent.

9. MIL-R-55342, RM (fixed, film, chip). Primarily intended for incorporation into hybrid microelectronic circuits. These resistors are uncased, leadless chip devices and have a high degree of stability with respect to time, under severe environmental conditions.

10. MIL-R-83401, RZ (networks, fixed, film). Resistor networks come in dual-in-line, single-in-line, or flat pack configuration. Use in critical circuitry where stability, long life, reliability, and accuracy are of prime importance. They are particularly desirable where miniaturization and ease of assembly are important.

Mounting Guide

Since improper heat dissipation is the predominant contributing cause of wear-out failure for any resistor type, the lowest possible resistor surface temperature should be maintained. The intensity of radiated heat varies inversely with the square of the distance from the resistor. Maintaining maximum distance between heat-generating components serves to reduce cross-radiation heating effects, and promotes better convection by increasing airflow. For optimum cooling without a heat sink, small, power resistors should have large leads of minimum length terminating in tie points of sufficient mass to act as heat sinks. All resistors have a maximum surface temperature that must not be exceeded. Resistors should be mounted so that there are no abnormal hot spots on the resistor surface. Most solid surfaces, including insulators, are better heat conductors than air.

Rating Factors

The permissible power rating of a resistor is another factor that is initially set by the use to which the circuit is put, but it is markedly affected by the other conditions of use. It is based on the hot-spot temperature the resistor will withstand while still meeting other requirements of resistance variation, accuracy, and life.

Self-generated heat in a resistor is equal to I^2R. It is a usual practice to calculate this value and to use the next larger power rating available in conjunction with the derating guides.

Ambient Conditions versus Rating. The power rating of a resistor is based on a certain temperature rise from a specified ambient temperature. If the ambient temperature is greater than this value, the amount of heat the resistor can dissipate is even less and must be recalculated.

Accuracy versus Rating. Because all resistors have a temperature coefficient of resistance, a resistor expected to remain near its measured value under conditions of operation must remain relatively cool. For this reason, all resistors designated as “accurate” are very much larger, physically, for a certain power rating than ordinary “nonaccurate” resistors. In general, any resistor, accurate or not, must be derated if it is to remain very near its original measured value when it is being operated.

Life versus Rating. If especially long life is required of a resistor, particularly when “life” means remaining within a certain limit of resistance drift, it is usually necessary to derate the resistor, even if ambient conditions are moderate and if accuracy by itself is not important. A good rule to follow when choosing a resistor size for equipment that must operate for many thousands of hours is to derate it to one-half of its nominal power rating. Thus, if the self-generated heat in the resistor is $^1/_{10}$ W, do not use a $^1/_8$ W resistor but a $^1/_4$ W size. This will automatically keep the resistor cooler, will reduce the long-term drift, and will reduce the effect of the temperature coefficient.

In equipment that need not live so long and must be small, this rule may be impractical, and the engineer should adjust his dependence on rules to the circumstances at hand. A “cool” resistor will generally last longer than a “hot” one and can absorb transient overloads that might permanently damage a “hot” resistor.

Pulsed Conditions and Intermittent Loads. RWR and RER wire-wound resistors can reliably withstand pulse voltages of much greater amplitude than permitted for steady-state operation. When a resistor is used in circuits where power is drawn intermittently or in pulses, the actual power dissipated with safety during the pulses can sometimes be much more than the maximum rating of the resistor. For short pulses the actual heating is determined by the duty factor and the peak power dissipated. Before approving such a resistor application, however, the design engineer should be sure of the following:

1. The maximum voltage applied to the resistor during the pulses is never greater than its permissible maximum voltage.
2. The circuit cannot fail in such a way that continuous excessive power can be drawn through the resistor.

3. The average power being dissipated is well within the rating of the resistor.

4. Continuous steep wavefronts applied to the resistor do not cause malfunctions because of electromechanical effects of high voltage gradients.

Encapsulants. Resistors embedded in encapsulants require special considerations. Generally, below 1 W all encapsulants raise local temperatures by 20 to 50 percent. Foams increase temperatures in all cases with the effect more pronounced as free air hot-spot temperatures become greater than 100°C. All are highly dependent on the installation's thermal configuration.

Resistor Derating

Resistors that have smaller temperature excursions have a narrower range of resistance shifts because of temperature effects and have slower aging shift rates. In addition, conditions for material and construction failure that may have escaped product testing proceed at a slower rate with lower temperatures and smaller temperature excursions. Derating, therefore, improves stability as well as reliability. For very low power stress, a possible exception is that of carbon composition resistors where a major cause of resistance shift is absorption of atmospheric moisture that can be baked out by moderate self-heating in service.

The resistor derating factors shown in Table 3.2.1 require the application of the principles illustrated in the preceding and following paragraphs. The percentages or ratios are applied to the characteristic or rating that is established, taking into consideration the temperature and duty cycle of actual operation.

Power Derating. The objective of power derating is to establish the worst-case hot-spot temperature for the resistor. The power dissipated by a resistor causes the temperature to rise above ambient by an amount directly proportional to the amount of power dissipated. The maximum allowable power can vary because of applied voltage and temperature.

Computations of derated power apply to the maximum power permissible under conditions of voltage and ambient temperature. The derating percentage is applied after the permissible power is determined from the specification rating when all conditions and recommendations are observed. For instance, chassis-mounted resistors are designed to conduct most of the heat through the chassis. Thus, power ratings require knowing the thermal resistivity of the mounting surface and its temperature. MIL-STD-1995 defines chassis areas upon which power ratings are based.

TABLE 3.2.1 Resistor Derating Factors

Resistor type	Military specifications (MIL-R-)	Style	Maximum permissible percentage of military specification stress rating		
			Rated power	Voltage*	Current
Wire-wound, accurate, fixed 1.0 percent	39005	RBR	50	80	
0.1 percent			25	80	
Wire-wound, power, fixed	39007	RWR	50	80	
Composition, insulated, fixed	39008	RCR	50	80	
Wire-wound, power, chassis-mounted, fixed	39009	RER	50	80	
Wire-wound, lead-screw-actuated	39015	RTR	50	80	70
Film, metal, fixed	39017	RLR	50	80	
Non-wire-wound, lead-screw-actuated	39035	RJR	50	80	70
Film, fixed, high stability	55182	RNR/RNC	50	80	
Chip, film, fixed	55342	RM	50	80	
Networks, film, fixed	83401	RZ	50	80	

*Voltage applied should be no more than the smaller of V_{d1} or V_{d2}.

Voltage Derating. The voltage should be derated to a percentage of the maximum allowable voltage as determined for the specification rating. This voltage may be limited by derated power as well as by the maximum voltage of the resistor. The derated voltage should be the smaller of

$$V_{d1} = C_u V_r \qquad \text{and} \qquad V_{d2} = \sqrt{P_d R} \tag{1}$$

where V_d = derated voltage
P_d = derated power
C_u = derating constant = (percent derating)/100
V_r = rated voltage
R = resistance value

For ohmic values above the critical value (which depends on the power rating of the device). RCR, RNR/RNC, RLR, and RBR resistors are voltage-limited rather than power-limited. The voltage limitation is related to dielectric breakdown rather than to heat dissipation.

Ratings, Military versus Commercial. The military ratings of resistors are realistic for long-life performance; commercial resistors with equivalent size, material, and leads which advertise superior ratings should have those ratings subjected to careful scrutiny. Of particular importance is the size (diameter) of the resistance wire used in wire-wound resistors (RWR and RER). The use of smaller wire, of course, allows for higher resistance values in a given size, but the smaller wire is very susceptible to failure. For resistors on cores (both wire-wound and film), the thermal conductivity of the core contributes to both total heat removal and uniformity of the temperature rise along the resistance element. Generally, a size comparison of the commercial resistor with the specified dimensions of a military part with equivalent ratings will indicate whether or not the commercial rating could be acceptable in a military application.

CAPACITOR DERATING FACTORS AND APPLICATION GUIDELINES

Capacitor Types

Electrostatic capacitors, widely used in electronic equipment, include mica, glass, plastic film, paper-plastic, ceramic, air, and vacuum. Electrolytic types are aluminum and tantalum foil and wet or dry tantalum slug. All are affected by three primary stresses: voltage, temperature, and frequency.

Environmental Factors

The characteristic behavior and service life of all capacitors are highly dependent on the environments to which they are exposed. A capacitor may fail when subjected to environmental or operational conditions for which the capacitor was not designed or manufactured. Many perfectly good capacitors are misapplied and will fail when they are used in equipment that subsequently must see environmental conditions that exceed, or were not considered in, the design capabilities of the capacitor. Designers must understand the safety factors built into a given capacitor, the safety factors they add of their own accord, and the numerous effects of circuit and environmental conditions on the parameters. It is not enough to know only the capacitance and the voltage ratings. It is important to know to what extent the characteristics change with age and environment.

Temperature Variations. Temperature variations have an effect on the capacitance of all types of capacitors. Capacitance change with temperature is directly traceable to the fact that the dielectric constant of the materials changes with temperature.

In general, the lower-dielectric-constant materials tend to change less with temperature.

Capacitance will vary up or down with temperature depending on the dielectric and construction. The temperature can cause two distinct actions to take place that will affect capacitance. Both the dielectric constant of the material and the spacing between the electrodes can be altered. Again, depending on the materials, these two actions tend to either reinforce or offset each other.

The capacitance of polarized dielectrics is a complex function of temperature, voltage, and frequency; nonpolarized dielectrics exhibit less change than polarized materials. Many dielectrics exhibit a very large decrease in capacitance with a relatively small decrease in temperature. The increased power factor at this temperature may raise the dielectric temperature sufficiently to recover lost capacitance. When a capacitor is initially energized at low temperatures, the capacitance will be a small percentage of the nominal value, and if the internal heating is effective, the thermal time constant of the capacitor must be considered.

The *operating temperature* and changes in temperature also affect the mechanical structure in which the dielectric is housed. The terminal seals, using elastomeric materials or gaskets, may leak because of internal pressure buildup. Expansion and contraction of materials with different thermal-expansion coefficients may also cause seal leaks and cracks in internal joints. Electrolysis effects in glass-sealed terminals increase as the temperature increases.

If the capacitor is operated in the vicinity of another component operating at high temperature, the flashpoint of the impregnant should be considered.

Voltage Rating. Voltage ratings of nonelectrolytic capacitors are uniformly based on some life expectancy before catastrophic failure at some temperature and some voltage stress, since catastrophic failures of capacitors are usually caused by dielectric failure. Dielectric failure is typically a chemical effect and, for hermetically sealed parts where atmospheric contamination of the dielectric does not contribute, is a function of time, temperature, and voltage. The time-temperature relationship is well expressed by assuming that the chemical activity, and therefore degradation, proceeds at a doubled rate for each 10°C rise in temperature; e.g., a capacitor operating at 100°C will have half the life of a similar one operating at 90°C.

Frequency. This is a capacitor stress most often overlooked by the circuit designer. There are both inductance and capacitance in each capacitor, and obviously, there is a resonant frequency. Depending upon the capacitor type, this resonant frequency may or may not fall in a range troublesome to the designer. In high-frequency applications, NPO ceramic, extended foil-film, mica, and glass capacitors are usually used.

Insulation Resistance. Increasing temperature usually reduces insulation resistance, increases leakage current and power factor/dissipation factor, and reduces the voltage rating of the part. Conversely, reducing temperature normally improves most characteristics; however, at cold temperature extremes some impregnants and electrolytes may lose their effectiveness. The time of electrification is most critical in the determination of insulation resistance. The effect of the insulation resistance value is also quite critical in many circuit designs and can cause malfunctions if its magnitude and variation with temperature are not considered. The dielectric strength decreases as the temperature increases.

Moisture. Moisture in the dielectric decreases the dielectric strength, life, and insulation resistance and increases the power factor of the capacitor. Capacitors operated in high humidities should be hermetically sealed.

Aging. The extent and speed of aging of a capacitor depend on the dielectric materials used in its construction. Aging does not affect glass, mica, or stable ceramic capacitors. The most common capacitors with significant aging factors are the medium-K and hi-K ceramic type (CKR series) and aluminum electrolytic types. Detailed aging and storage-life data are given in MIL-STD-198.

External Pressure. The altitude at which hermetically sealed capacitors are to be operated will control the voltage rating of the capacitor terminals. As barometric pressure decreases, the ability of the terminals to withstand voltage arcing also decreases. External pressure is not usually a factor to be considered unless it is sufficient to change the physical characteristics of the container housing, the capacitor plates, and the dielectric. Heat transfer by convection is decreased as the altitude is increased. Certain high-density CKR-type capacitors demonstrate piezoelectric effects.

Shock, Vibration, and Acceleration. A capacitor can be mechanically destroyed or damaged if it is not designed or manufactured to withstand whatever mechanical stresses are present in the application. Movement of the internal assembly inside the container can cause capacitance changes and dielectric or insulation failures because of the physical movement of the electrode and fatigue failures of the terminal connections. The capacitors and mounting brackets, when applicable, must be designed to withstand the shock and vibration requirements of the particular application. Internal capacitor construction must be considered when selecting a capacitor for a highly dynamic environment.

Series Impedance. For solid tantalum electrolytic capacitors, the traditional criterion for their application was to ensure that the circuit provided for a minimum of 3 Ω of impedance for each volt of potential (3 Ω/V) applied to the capacitor. However, advances in the state of the art in recent years (in the control of the purity of tantalum powder and in manufacturing technology) make it possible to use these capacitors in circuits with series impedance as low as 0.1 Ω/V, without a significant impact on equipment reliability. For reliable operation follow these ground rules:

1. Never select the highest voltage rating and capacitance value in a given case size. These parts represent the ultimate in manufacturing capability, are costly, and are a reliability risk.
2. Never select a voltage rating greater than that needed to satisfy the voltage derating criteria herein. The higher voltage ratings require thicker dielectrics, increasing the probability of the inclusion of impurities. Also, the

TABLE 3.2.2 Derating Factors for Capacitors

Capacitor type	Military specifications (MIL-C-)	Style	Maximum permissible percentage of military specification stress rating[a]			
			Voltage[b]	Current[c]	AC ripple	Surge
Fixed, ceramic, temperature-compensating (ER)	20	CCR	50	70		
Fixed, feedthrough	11693	CZR	70	70		
Fixed, paper-plastic (ER), and plastic film (ER)	19978	CQR	70	70	70	70
Fixed, glass (ER)	23269	CYR	75	70	70	70
Fixed, mica (ER)	39001	CMR	80	70	70	70
Fixed, electrolytic tantalum, solid (ER)	39003	CSR[d]	50	70	70	
Fixed, electrolytic tantalum, nonsolid (ER)	39006	CLR	50	70		
Fixed, electrolytic all tantalum nonsolid (ER)	39006/22	CLR 79	80	80[e]		
Fixed, ceramic (ER) (general purpose)	39014	CKR	60	70	70	70
Fixed, electrolytic, aluminum (ER)	39018	CUR	80 min 95 max	75		
Fixed, metallized paper-film (ER)	39022	CHR	50	70	70	70
Chip, fixed, tantalum solid (ER)	55365	CWR	50	70		
Fixed, plastic-film DC or DC-AC, (ER)	55514[f]	CFR	60	70	70	70
Chip, fixed, ceramic (ER)	55681	CDR	60	70		
Fixed, plastic-film DC, AC, or DC-AC	83421	CRH	60	70	70	70

[a] Manufacturer's derating factors must be applied before applying these factors.
[b] Voltage equals instantaneous total of dc, ac, surge, and transient voltage.
[c] Rated current is defined as $I_R = \sqrt{P_{\text{max}} / R_{\text{max}}}$ and by limiting the current to 0.70 times rated current, power is limited to 0.50 maximum.
[d] Limited to 85°C ambient temperature.
[e] Package for maximum thermal dissipation.
[f] Not hermetically sealed.

lower-voltage-rated parts will typically have smaller slug sizes, which results in a greater internal equivalent series resistance (ESR), which tends to compensate for the reduction of the external series resistance.

3. Always specify the lowest established reliability failure rate available from two or more suppliers. S-level parts are typically manufactured under more rigorous process controls than higher-failure-rate-level parts.

Commercial versus Military-Type Capacitors. Valid conclusions can be reached concerning life and reliability to be expected from commercial capacitors by comparing their values with those of similar military capacitors of the same dielectric and capacitance. If the commercial capacitor is appreciably smaller than the corresponding military device, it can be safely assumed that the commercial unit has a shorter life and is less reliable.

Capacitor Derating

The capacitor derating factors (Table 3.2.2) should be applied after all derating (stated or implied by the MIL-SPEC or manufacturer) has been applied in the circuit design. The table shows the maximum allowable percentage of voltage and current.

Precautions. The following checklist will help achieve high reliability:

- Do not exceed the current rating on any capacitor, taking into account the duty cycle. Provide series resistance or other means in charge-discharge circuits to control surge currents.
- Include dc, superimposed peak ac, peak pulse, and peak transients when calculating the voltage impressed on capacitors.
- The MIL-SPEC or manufacturer's recommendations for frequency, ripple voltage, temperature, and so forth, should also be followed for further derating.

SEMICONDUCTOR DERATING FACTORS AND APPLICATION GUIDELINES

General Considerations

Semiconductor device derating should be applied after all deratings stated or implied by the part MIL-SPEC have been used in the circuit design.

For designs using silicon active components, transistors, and diodes, the maximum junction temperature must not exceed 110°C for ground and airborne applications. If the maximum rated junction temperature of the device is ≤150°C, the maximum junction temperature for missile-flight applications must not exceed 110°C. If the maximum rated junction temperature of the device is ≥175°C, the maximum junction temperature for missile-flight applications must not exceed 140°C. (See Table 3.2.3.)

A maximum power rating on any semiconductor device is by itself a meaningless parameter. The parameters of value are maximum operating junction temperature, thermal resistance, and/or thermal derating (reciprocal of thermal resistance). For all semiconductor devices, the mechanism for removal of heat from a junction is usually that of conduction through the leads, not convection. For all silicon transistors and diodes, the maximum operating junction temperature should be 110 or 140°C, respectively.

The method for calculating device junction temperature is

$$T_J = T_A + \theta_{J-A} P_D \tag{2}$$

where T_j = junction temperature
T_A = maximum ambient temperature at component
θ_{J-A} = thermal resistance from junction to air
P_D = power dissipated in device

TABLE 3.2.3 Transistor Derating Factors

Parameter	Derating factor*
Voltage (V_{CEO}, V_{CBO}, V_{EBO})	0.75
Current	0.75
Junction temperature:	
Ground and airborne use	110°C
Missile-flight use ($T_1 \leq 150$°C)	110°C
Missile-flight use ($T_1 \geq 175$°C)	140°C
Allowing for:	
Increase in leakage (l_{CBO} or I_{CEO})	+100 percent
Increase in h_{FE}	+50 percent
Decrease in h_{FE}	–50 percent
Increase in $V_{CE(SAT)}$	+10 percent

*Derating factor (applicable to all transistor types) = Maximum allowable stress/Rated stress

where heat sinks are used, the expression is expanded to

$$T_J = T_A + (\theta_{J-C} + \theta_{C-S} + \theta_{S-A})P_D \tag{3}$$

where

$$\theta_{J-C} + \theta_{C-S} + \theta_{S-A} = \theta_{J-A}$$

where θ_{C-S} = thermal resistance between case to heat sink (usually includes mica washer and heat-sink compound)
θ_{S-A} = thermal resistance of heat sink
θ_{J-C} = thermal resistance from junction to case

Examples for calculation of junction temperature for various conditions follow.

Thermal Resistance and Power Calculations

Using the types of inputs described above, the following examples demonstrate the ease with which thermal calculations can be performed.

Example 1. Given: 1N753 reference diode: find; θ_{J-A}. Specifications: $P_D = 400$ mW (max power), $T_J = 175$°C (max junction), $T_A = 25$°C (max ambient).

The manufacturer does not give θ_{J-A}, but it can be calculated using the above data. The maximum power dissipation is calculated from specified maximums at room temperature:

$$T_J = T_A + \theta_{J-A}P_D$$

$$175°\text{C} = 25°\text{C} + (\theta_{J-A})(0.4)$$

$$\theta_{J-A} = 375°\text{C/W}$$

Example 2. Determine the thermal resistance of a heat sink required for a 2N3716 power transistor that is to dissipate 14 W at an ambient temperature of 70°C.

$$\theta_{J-C} = 1.17°\text{C/W} \qquad \text{from 2N3716 specifications}$$

$$\theta_{C-S} = 0.5°\text{C/W}$$

TABLE 3.2.4 Contact Thermal Resistance of Insulators

Insulator	Thickness, in	θ_{C-S}, °C/W
No insulation	. . . . .	0.4
Anodized aluminum	0.016	0.4
	0.125	0.5
Mica	0.002	0.5
	0.004	0.65
Mylar	0.003	1.0
Glass cloth (Teflon-coated)	0.003	1.25

($\theta_{C-S} = 0.5$°C/W for mica washer; Table 3.2.4

$$110°\text{C} = 70°\text{C} + \theta_{J-A}P_D$$

$$\theta_{J-A} = (110 - 70)\frac{1}{P_D} = \frac{40}{14} \approx 2.9°\text{C/W}$$

$$\theta_{J-A} = \theta_{J-C} + \theta_{C-S} + \theta_{S-A}$$

$$2.9 = 1.17 + 0.5 + \theta_{S-A}$$

$$\theta_{S-A} \leq 1.23°\text{C/W}$$

(Heat-sink thermal resistance required; note Table 3.2.5 for thermal resistance of some common commercially available heat sinks. The lowest value of thermal resistance results in the lowest junction temperature of the part.)

Example 3. Determine the maximum power that the 2N3716 can dissipate without a heat sink in an ambient of 70°C;

$$\theta_{J-A} = 35°\text{C/W}$$

(Not given on Motorola data sheets, but for almost all TO-3 devices $\theta_{J-A} = 35$°C/W; see Table 3.2.6.)

$$T_J = T_A + \theta_{J-A}P_D$$

$$P_D = \frac{T_J - T_A}{\theta_{J-A}} = \frac{110 - 70}{35} = 1.14\text{ W}$$

Example 4. Determine the maximum power that can be dissipated by a 2N2222 transistor (missile-flight use) with an ambient temperature of 70°C. Derating given: 3.33 mW/°C for 2N2222, TO-18. Therefore

$$\theta_{J-A} = \frac{1°\text{C}}{3.33\text{ mW}} = 300°\text{C/W}$$

and

$$P_D = \frac{T_J - T_A}{\theta_{J-A}} = \frac{140 - 70}{300} = 233\text{ mW}$$

TABLE 3.2.5 Thermal Resistance of Heat Sinks

Shape	Surface area, in	Volume displacement				wt, g	Finish	Thermal resistance, °C/W
		L, in	*W*, in	*H*, in	Vol, in			
Extrusion								
Flat-finned	65	3.0	3.6	1.0	10.8	114	Anod black	2.4
							Bright alum	3.0
							Gray	2.8
	60	3.0	4.0	0.69	8.3	123	Anod black	2.8
	95	3.0	4.0	1.28	15.3	189	Anod black	2.1
	64	3.0	3.8	1.3	15.0	155	Black paint	2.2
	83	3.0	4.0	1.25	15.0	140	Anod black	2.2
	44	1.5	4.0	1.25	7.5	75	Anod black	3.0
	137	3.0	4.0	2.63	31.5	253	Anod black	1.45
	250	5.5	4.0	2.63	58.0	461	Anod black	1.10
	130	6	3.6	1.0	21.5	253	Anod black	1.75
	78	3.0	3.8	1.1	12.5	190	Anod gray	2.9
	62	3.0	3.8	1.3	15.0	170	Anod gray	2.2
	78	3.0	4.5	1.0	13.5	146	Gold alodine	3.0
Machined casting								
Cylindrical fins, horizontal	30	1.75		0.84	2.0	40	Anod black	8.5
	50	1.75		1.5	3.6	67	Anod black	7.1
	37	1.75		1.5	3.6	48	Anod black	6.65
Casting								
Cylindrical fins, vertical	7.5	1.5		0.9	4.4	33	Anod black	8.1
	12	1.5		1.4	6.9	51	Anod black	7.0
	25	1.5		2.9	14.2	112	Anod black	5.6
	35	1.5		3.4	16.7	132	Anod black	5.1
	32	2.5		1.5	7.4	94	Anod black	4.5
	20	2.5		0.5	2.45	48	Anod black	6.6
Flat-finned	23	1.86	1.86	1.2	4.15	87	Anod black	5.06
Sheet-metal								
Vertical fins, square	12	1.7	1.7	1.0	2.9	19	Anod black	7.4
Cylindricals	15	2.31*		0.81	3.35	18	Black	7.1
Horizontal fins, cylindrical	6	1.81*		0.56	1.44	20	Anod black	9.15
	55	2.5		1.1	5.4	115	Gold irridate	7.9

*Diameter.

Semiconductor Derating

Power Derating. The objective of power derating is to hold the worst-case junction temperature to a value below the normal permissible rating. The typical diode specification for thermal derating expresses the change in junction temperature with power for the worst case. The actual temperature rise per unit of power will be considerably less, but this is not a value that can readily be determined for each unit.

Junction-Temperature Derating. Junction-temperature derating requires the determination of ambient temperature or case temperature. The worst-case ambient temperature or case temperature for the part is established for the area and for the environmental conditions that will be encountered in service. The ambient temperature for a

TABLE 3.2.6 Thermal Resistance of Packages, °C/W

Package type	Still air θ_{J-A}	Still air θ_{J-C}
TO-3	30–50	1.0–3.0
TO-66	30–50	4.0–7.5
TO-5	100–300	30–90
TO-18	300–500	150–250
TO-99, TO-100	197	60
Flat pack:		
14 lead	200	70
16 lead	195	68
24 lead	170	55
Ceramic dip:		
8 lead	125	50
14 lead	110	50
16 lead	110	50
18 lead	100	40
20 lead	100	40
22 lead	100	40
24 lead	100	40
40 lead	80	30
Leadless chip carrier:		
16 castellation	—	60
20 castellation	—	60
24 castellation	—	60
28 castellation	—	60
44 castellation	—	60
Plastic dip	150	80

device that does not include some means for thermal connection to a mounting surface should include the temperature rise because of the device, adjacent devices, and any heating effect that can be encountered in service.

Voltage Derating. The voltage rating of a semiconductor device can vary with temperature, frequency, or bias condition. The rated voltage implied by the tabulated rating is the voltage compensated for all factors determined from the manufacturer's data sheet. Derating consists of the application of a percentage figure to the voltage determined from all factors of the rating. Three distinct deratings cover the conditions that can be experienced in any design situation.

1. *Instantaneous peak-voltage derating* is the most important and least understood derating. It is required to protect against the high-voltage transient spike that can occur on power lines as a result of magnetic energy stored in inductors, transformers, or relay coils. Transient spikes also can result from momentary unstable conditions that cause high amplitude during switching turnon or turnoff.

   Transient spike or oscillating conditions in test sets or life-test racks or resulting from the discharge of static electricity will cause minute breakdown of surface or the bulk silicon material.

   Lightning transients, which enter a circuit along power lines or couple from conducting structural members, are a frequent cause of failure or of damage that increases the probability of failure during service.
2. The *continuous peak voltage* is the voltage at the peak of any signal or continuous condition that is a normal part of the design conditions.
3. The *design maximum voltage* is the highest average voltage. This is essentially the dc voltage as read by a dc meter. The ac signals can be superimposed on the dc voltage to produce a higher peak voltage, providing the continuous peak voltage is not exceeded.

Transistor Guidelines

The major failure modes are the degradation of h_{FE} and increased leakage with prolonged use at elevated temperatures. Depending on the application, this parameter degradation can result in a catastrophic failure or decrease in system performance outside the bound of the worst-case design. It is necessary to maintain the junction operating temperature below 110°C for ground and airborne use (140°C for missile-flight use if device rated $T_J \geq 175°\text{C}$). The principle design criteria for silicon transistors are shown in Table 3.2.3. This derating is applicable to all transistor types.

Transistor Application Information. These general guidelines apply:

- h_{FE} has a positive temperature coefficient. This criterion may not be valid for some power transistors operating at high current levels where h_{FE} decreases with temperature.
- If a maximum leakage is specified at 110°C for ground and airborne use (140°C for missile use if device rated $T_J \geq 175°\text{C}$), double the leakage value for end of life condition.
- The ratings of Table 3.2.3 apply for operating junction temperature, not just ambient temperature.
- Typical thermal resistances for common case sizes are described in Table 3.2.6.

Thermal Resistance and Heat Sinks. Table 3.2.4 lists contact thermal resistance for various insulators, and Table 3.2.5 gives the thermal resistance for various heat sinks. Figure 3.2.1 is used to calculate θ_{S-A} for solid copper or aluminum plates. This is helpful in determining the thermal capabilities of metal chassis. Note that a vertically mounted plate has better thermal properties than a horizontally mounted plate. A list of approximate thermal resistances for various package sizes is given in Table 3.2.6.

Diode Guidelines

The junction-temperature limits specified for semiconductors apply to all diodes. For non-heat-sinked components, a quick calculation can be made to determine the power a given device may dissipate. The calculation described in "Thermal Resistance and Power Calculations," p. 3.28, can be used to determine this parameter. The derating for silicon diodes is given in Table 3.2.7.

For zener diodes, the best worst-case end-of-life tolerance that can be guaranteed is ±1 percent. This places a limitation on the final accuracy of any analog system end of life at some value greater than 1 percent.

Zener-Diode Voltage-Variation Calculation. The change in zener voltage over a specified operating range is primarily a function of the zener temperature coefficient (TC) and dynamic resistance. The temperature to be used for the TC is the junction temperature of the device in question.

Given: 1N3020B; 10-V zener ±5 percent (add 1 percent end of life)

$$P = 1\text{ W} \qquad \text{derate } 6.67\text{ mW/°C}$$

$$Z_z = 7\ \Omega \qquad \text{at } 25\text{ mA} = I_{zT}$$

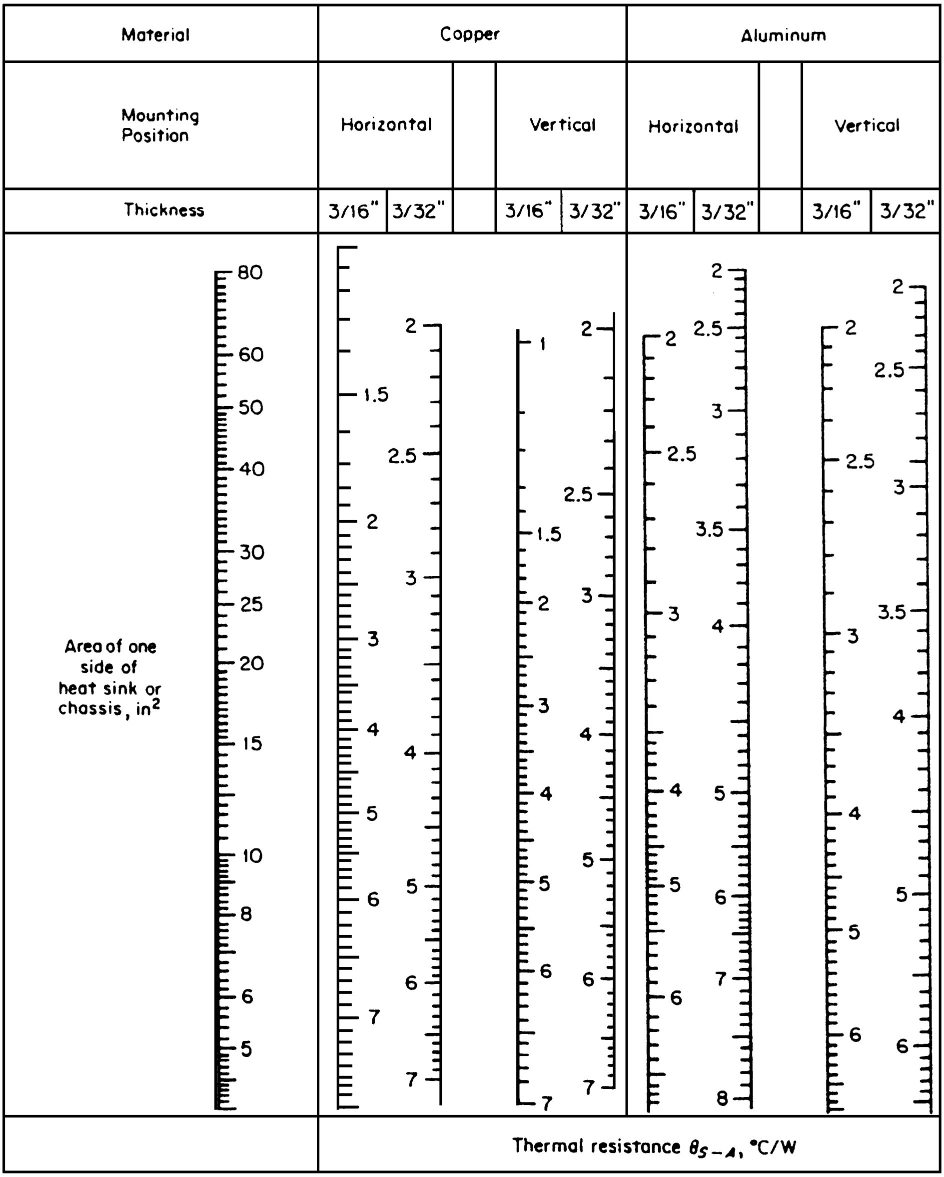
$$\text{TC} = 0.055\text{ percent/°C} \qquad V_{CC} = 30\text{ V} \pm 5\text{ percent (See Fig. 3.2.2.)}$$

The ambient range is –25 to 70°C, V_{CC} (applied through a resistor R) = 30 V ±5 percent, and R = 800 ±20 percent.

(*a*) Calculation for the worst-case maximum power of zener and θ_{J-A}

$$P = V_z I_z \qquad \text{neglect TC initially}$$

$$= (10.6\text{ V})\frac{31.5 - 10.6}{640}$$



Instructions for use: Select the heat sink area at left and draw a horizontal line across the chart from this value. Read the values of θ_{S-A} depending on the thickness of the material, type of material, and mounting position.

FIGURE 3.2.1 Thermal resistance as a function of heat-sink dimensions.

TABLE 3.2.7 Silicon Diode Derating Factors

Parameter	Factor*
Voltage	0.75
Current	0.75
Junction temperature, ground and airborne use	110°C
Missile-flight use ($T_1 \le 150$°C)	110°C
Missile-flight use ($T_1 \ge 175$°C)	140°C
Allowing for:	
Increase in leakage l_R	+100 percent
Increase in V_F	+10 percent

$$^*\text{Derating factor} = \frac{\text{maximum allowable stress}}{\text{rated stress}}$$

$$= (10.6)(32.7\text{ mA}) = 0.347\text{ W}$$

$$\theta_{J-A} = \frac{1°\text{C}}{6.67\text{ mW}} = 149°\text{C/W}$$

(*b*) Calculation for maximum junction temperature

$$T_J = T_A + P_D\theta_{J-A} = 70°\text{C} + (0.347)(149°\text{C/W}) = 121.7°\text{C}$$

(*c*) Calculation for minimum power in zener

$$P = V_z I_z = (9.4)\frac{28.5 - 9.4}{960} = 0.180\text{ W}$$

(*d*) Calculation for minimum junction temperature

$$\begin{aligned} T_J &= T_A + P_D\theta_{J-A} \\ &= -25°\text{C} + (0.180)(149°\text{C/W}) = 1.8°\text{C} \end{aligned}$$

(*e*) Calculation for overall maximum V_z

$$\begin{aligned} V_z &= V_{z.\text{MAX}} + I_z Z_z + (T_J - T_{\text{amb}})(\text{TC})(V_z) \\ &= 10.6\text{ V} + (32.7\text{ mA})(7) + (121.7 - 25)(0.00055)(10) \\ &= 11.36\text{ V} \end{aligned}$$

(*f*) Calculation for overall minimum V_z

$$\begin{aligned} V_z &= V_{z.\text{MIN}} - I_z Z_z - (T_{\text{amb}} - T_J)(\text{TC})(V_z) \\ &= 9.4 - (19.1)(7) - (25 - 1.8)(0.00055)(10) = 9.138\text{ V} \end{aligned}$$

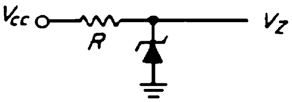


FIGURE 3.2.2 Zener diode V_{CC}.

Several iterations may be necessary to determine maximum and minimum zener voltages, because steps (a) and (c) used 10.6 and 9.4 V, respectively, for computing maximum and minimum V_z, while we calculate 11.36 and 9.138. This affects *P*, which in turn affects the TC term of V_z and maximum and minimum zener currents.

TABLE 3.2.8 Microcircuit Derating Factors*

Type	Open mounting	Enclosed	Parameter
Digital	0.80	0.70	Fanout/output current
	0.75	0.75	Supply voltage†
	0.75	0.75	Operating frequency
	90°C max	90°C max	C/MOS junction temperature
	100°C max	100°C max	Junction temperature
	110°C max	110°C max	TTL junction temperature
Linear or hybrid	0.80	0.80	Supply voltage†
	0.75	0.65	Output voltage
	0.75	0.75	Operating frequency
	100°C max	100°C max	Junction temperature
	105°C max	105°C max	Hybrid junction temperature

*Derating factor = $\dfrac{\text{maximum allowable stress}}{\text{rated stress}}$

†For devices with dynamic supply voltage ranges only; all others will use manufacturers' recommended supply voltage. Derating below 75 percent of the supply voltage may cause the device to operate below recommended operating voltages.

Integrated-Circuit Guidelines

Derating is a process that improves in-use reliability of a component by reducing the life stress on the component or making numerical allowances for minor degradation in the performance of the component. This technique is applied to integrated circuits in two separate and distinct ways.

The first is to specify a derating factor in the application of the component. Derating factors (Table 3.2.8) are applied to the voltage, current, and power stresses to which the integrated circuit is subjected during operation. Derating factors must be applied knowledgeably and singly; i.e., they must be applied only to a degree that improves reliability, and they must be applied only once throughout the entire cycle that stretches from the design of the integrated circuit to its application in a system.

From the outset, integrated circuits are designed to a set of conservative design-rating criteria. The currents that flow through the conductors and through the wire bonds on a chip, the voltages applied to the semiconductor junctions, and the overall power stress on the entire chip are conservatively defined during the design of an integrated circuit. Therefore it may not be appropriate to derate the integrated circuit further in its application. Derating power consumption of a digital integrated circuit may not be possible, since the circuit must operate at a specified level of power-supply voltage for maximum performance. However, some linear circuits designed to operate over an extended range of power-supply voltages and power dissipations may accept some degree of derating when it is appropriately applied.

Thus, the main area of derating in integrated circuits in not in derating the *stresses* applied to the circuit but in derating the expected and required *performance.* The designer must fully recognize potential performance degradation of integrated circuits over their life. This parametric degradation can require using a digital circuit at less than its full fanout. It can mean designing for an extra noise margin, sacrificing some of it to the degradation of the integrated circuit. It can also mean applying the integrated circuit at performance levels below those guaranteed by the circuit's characterization-specification sheet.

Establishment of derating factors for integrated-circuit parameters must be made after careful analysis of each particular parameter in the circuit. Parameters depending directly on transistor beta, resistor value, or junction leakage are most prone to shift during life. Parameters depending directly on the saturation voltages of junctions and on the ratios of resistors are most likely to remain stable. For digital microcircuits, device fanout should be derated by a factor of 20 percent, logic noise-margin levels should be derated by a factor of 10 percent, and the maximum operating frequency should be derated by a factor of 25 percent. For linear microcircuits, the input offset and input signal voltages should be derated by a factor of 20 percent. The output current and maximum operating frequency should be derated by a factor of 25 percent.

The severity of the application further establishes the degree of proper derating. It is not customary to derate ac parameters, such as delay times or rates, as these parameters do not vary greatly over the life of an integrated circuit. Allowances should be made, however, for unit-to-unit variation within a given integrated-circuit chip. The delay times of separate gates within one integrated-circuit package can vary greatly. These parameters are usually not measured on 100 percent of the units.

Although one may be able to derate an integrated circuit for reliability in specified special cases, one cannot take advantage of the derating designed into the integrated circuit and use it beyond its rating or specified capability.

TRANSFORMER, COIL, AND CHOKE DERATING

General Considerations

The ratings and deratings of transformers, chokes, and coils are covered in the following paragraphs. Transformers are frequently designed for a particular application and can become a major source of heat. Two major considerations result: derating of transformers must include consideration of their heating effects on other parts; and transformer derating requires control of ambient plus winding-temperature rises.

Voltage Derating

Winding voltages are fixed voltages and cannot be derated to any significant degree as a means of improving reliability. The voltages present between any winding and case or between any winding and shield, as specified, should be derated in accordance with the voltage derating factors of Table 3.2.9.

Power Derating

The power dissipated in a transformer should be derated to control the winding temperature to the maximum derated temperature under full load conditions that are normal to the worst-case service conditions.

Temperature rise is determined for service conditions by measurement of winding resistance using the procedure of MIL-T-27B.

The insulation grade of a transformer is rated for a maximum operating temperature. Deratings shown in Table 3.2.9 are allowances of temperature to be subtracted from the rated temperature to determine derated temperature. All considerations of frequency, hot-spot temperature, and other factors included in the manufacturer's data must be allowed for before applying this reliability derating temperature.

TABLE 3.2.9 Coil, Transformer, and Choke Derating Factors

	Maximum permissible percent of manufacturer's stress rating			
	Insulation breakdown voltage			
Type	Maximum	Transient	Operating current, A	Allowable winding temp rise, °C
		Coil		
Inductor, saturable reactor	60	90	80	30
General	60	90	80	30
RF, fixed	60	90	80	35
		Transformer		
Audio	50	90	80	35
Pulse, low-power	60	90	80	30
RF	60	90	80	30
Saturable-core	60	90	80	30

Current Derating

The maximum current in each winding should be derated in accordance with the percentage deratings shown in Table 3.2.9. The derated current should be considered as the largest current that can flow in the winding under any combination of operating conditions.

In-rush transient currents should be limited to the maximum allowable in-rush or surge rating of the transformer, as shown in Table 3.2.9. The current in all windings should not cause a power dissipation or temperature in excess of the derated temperature requirements.

SWITCHES AND RELAYS

Switch Considerations

Switches are to be applied in circuits with operating current loads and applied voltages well within the specified limits of the type designated. A major problem is contamination, which includes particles and contaminant films on contacts. The storage life on switches may exceed 10 years if they are hermetically sealed. The cycle life for switches can be in excess of 100,000 cycles.

Switch Derating

The contact power (volt-amperes) for general-purpose switches (1 to 15 A) should be derated as shown in Table 3.2.10 from the maximum rated contact power within the maximum current and voltage ratings.

Temperature. Switches should not be operated above rated temperature. Heat degrades insulation, weakens bonds, increases rate of corrosion and chemical action, and accelerates fatigue and creep in detent springs and moving parts. The derating factor in Table 3.2.10 is defined as the maximum allowable stress divided by the rated stress.

For capacitor loads, capacitive peak in-rush current should not exceed the derated limit. If the relay-switch specification defines inductive, motor, filament (lamp), or capacitive load ratings, they should be derated 75 percent instead of the derating specified in Table 3.2.10.

Relay Considerations

Relays are to be used in circuits with operating current load and applied coil and contact voltage well within specified ratings. The application for each device should be reviewed independently.

Relay cycle life varies from 50,000 to more than 1 million cycles depending on the relay type, electrical loads of the contacts, duty cycle, application, and the extent to which the relay is derated. The storage life of hermetically sealed relays, with proper materials and processes employed to eliminate internal outgassing, is over 10 years.

TABLE 3.2.10 Relay and Switch Derating Factors

Type of load	Percent of rated value
Resistive	75
Inductive	40
Motor	20
Filament	10
Capacitive	75
Contact power[*]	50

[*] Applicable to reed, mercury-wetted, or other loads rated in watt or volt-amperes.

The chief problem in electromechanical relays is contamination. Even if cleaning processes eliminate all particulates, the problem of internal generation of particles, owing wear, is still present.

Relay Derating

The contact power (volt-amperes) should be derated as shown in Table 3.2.10 from the maximum rated stress level for loads of 1 to 15 A.

Film formation on relay contacts, as discussed in Chap. 5.4 can cause excessive resistance. This can be a serious reliability problem with contacts that switch very low voltage or when relays are subjected to long periods of dormancy. Hermetically sealed relays are recommended for military applications, and vendors should be consulted to determine if a particular device is rated for “dry contact” service.

Resistive Loads. The resistive load is basically what is used to rate relays and what most designers use when calculating the size of the relay needed for a particular circuit. In a resistive load the current flow is practically constant, with the exception of some minor arcing on make or break. As long as the limits of the contacts are not exceeded, the relay should operate reliably throughout its rated life. Unfortunately, this ideal standard is sometimes the most difficult to find in “real world” engineering. When applying derating to a purely resistive load, accepted industry practice would suggest going to 75 percent of the rated value for the device in question.

Capacitive Loads. The in-rush current in a capacitive load can be very high. This is due to the fact that a capacitor, when charging, acts as a short circuit limited only by whatever resistance may be in the circuit. Therefore, the best way to control this initial surge, and thereby protect the relay contacts, is to add a series limiting resistance. Without the series limiting resistance, contact welding or contact deterioration will shorten the life of the relay. Accepted industry practice would suggest that a derating of 75 percent of the resistive load rating should be applied. Should the relay in question already have a capacitive rating, the same 75 percent of this rating would apply.

Inductive Loads. Inductors, transformers, coils, chokes, and solenoids are all high inductive loads. In-rush currents may or may not be a problem with such loads, particularly with transformers and solenoids. However, when the circuit is broken, the stored energy in the collapsing magnetic field is dissipated across the opening contacts. The resultant arcing will cause excessive contact deterioration. This situation will be further aggravated when the load circuit has a long time constant. When size and weight preclude the use of a relay with sufficient capacity to handle the transient conditions, arc-suppression circuits should be added. These can be as simple as a diode to a diode-*RC* network. An added benefit to such circuits will be increased contact life. Accepted industry practice would be to derate the contacts to 40 percent of their resistive load rating. If the relay in question has an inductive load rating, then the derating should be 75 percent of this specified value.

Motor Loads. A motor, in the nonrunning condition, has a very low input impedance and consequently a large in-rush current. As the current starts to flow through the windings, a torque is developed because of the interaction of the magnetic field in the motor and the current in the winding. As the armature of the motor begins to turn, it generates a back emf in the opposite direction of the original applied voltage thus reducing the current flow. However, the greater the load on the motor, the longer the starting time and thus the longer the high starting current will persist in the circuit. Conversely, when the applied voltage is removed, a high inductive spike is produced. Therefore, on turn-on the controlling relay contacts will see very high in-rush currents, for a varying period of time, depending on the motor load: conversely on turnoff, an arc will be produced across the opening contacts. Accepted industry practice for motor loads would suggest a derating to 20 percent of the resistive load rating of the relay. If, however, the relay in question has a motor load rating then the derating should be 75 percent of this specified value.

Incandescent Lamp Loads. An incandescent lamp filament is considered to be a resistive load. When cold, the resistance of the filament is very low. When power is applied, an in-rush current results that can be as much as 15 times greater than the final steady-state value. The magnitude of these in-rush currents can cause the contacts to either weld shut or degrade to the point where they can no longer be used. Accepted industry practice would be to derate the contacts to 10 percent of their resistive load ratings. If, however, the specific relay in question already has a lamp load rating, then the derating should be 75 percent of this specified value. Good design practice would also dictate that, wherever possible, a series current limiting resistor be used to control these in-rush currents.

Relay Coils. Coils should not be derated. Any change from nominal voltage, other than ±5 percent tolerance, can have a serious effect on the operation of a relay.

Temperature. Relays should not be operated above rated temperature because of resulting increased degradation and fatigue. The best practice is to derate 20°C from the maximum rated temperature limit.

CIRCUIT BREAKERS, FUSES, AND LAMPS

Circuit Breakers

Circuit breakers should be sized for each application to protect the circuit adequately from overvoltage or overcurrent. For optimum reliability *thermal circuit breakers* should not be subjected to operation in environments where temperatures vary from specified rating(s) because the current-carrying capability of the sensing element is sensitive to temperature variations. For optimum reliability *magnetic circuit breakers* should not be subjected to dynamic environments exceeding the device limitations.

Derating should depend on the type of circuit breaker or circuit being protected. Normally, circuit breakers of the magnetic type, which are relatively insensitive to temperature, should not be derated except for the interrupting capacity, which should be derated up to 75 percent of maximum rated interrupting capacity. Derating of standard circuit breakers used in high-reactance-type circuits may be required to avoid undesired tripping from high in-rush current.

Thermal-sensitive circuit breakers used outside of specified ratings should be derated to compensate for effects of operating ambient temperatures.

Fuses

Fuses should have ratings that correspond to those of the parts and circuits they protect. These fuse ratings should be compatible with starting and operating currents as well as ambient temperatures. Current-carrying capacity may vary with temperature. An example is given in MIL-F-23419/9.

Fusing should be arranged so that fuses in branch circuits will open before fuses in the main circuit.

Indicator Lamps

Incandescent and gaseous indicator lamps should be protected from voltage or current surges above ratings.

Derating. Operating incandescent lamps at 94 percent of rated voltage will double the life of the lamp, with only a 16 percent drop in light output. Current is the principal stress parameter for gaseous lamps. Derating current to 94 percent of the lamp's rating will double the life expectancy.

Leds

Temperature and current are the primary stress parameters for light-emitting diodes. The designer should keep maximum junction temperature below 105°C and should maintain average forward current at a level no greater than 65 percent of the rated value.

BIBLIOGRAPHY

Ramakrishnan, A., T. Syrus, and M. Pecht, "Electronic Hardware Reliability," CALCE Electronic Products and Systems Center, University of Maryland.

ASFC PAM 800-27, "Part Derating Guidelines."

U.S. Dept. of the Air Force Military Standard Technical Requirements for Parts, Materials, and Processes for Space and Launch Vehicles, MIL-STD-1547 (USAF).

U.S. Dept. of Defense, "Resistors: Selection and Use of," MIL-STD-199.

U.S. Dept. of Defense, "Capacitors: Selection and Use of," MIL-STD-198.

U.S. Dept. of Defense, "Transformer, Audio Frequency," MIL-T27.

U.S. Dept. of Defense, "Fuse Instrument Type Style FM09 (Non-indicating)," MIL-STD-F23419.