START Selected Topics in Assurance Related Technologies

Volume 11, Number 7

Derating

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Introduction

Derating can be defined as "the practice of limiting electrical, thermal and mechanical stress on parts, in a given design application, to levels that are below their specified ratings or their proven capabilities in order to enhance reliability". Reducing these stresses extends part life and usually, but not always (depending upon the nature of the part and the specific parameter involved) improves part reliability and hence system reliability. In addition, derating helps protect parts from unforeseen application anomalies and overstresses.

Derating is a structured engineering approach to part application tailored to deal with, among other things, part variability. All parts do not have the same "strength." Part "strength" variability within any given population of parts is a fact of life and derating helps to compensate for this variability. Even parts from a so-called homogenous population, the same production line and from the same "production lot" exhibit some parameter variability. When so-called "interchangeable parts" are supplied by different manufacturers, possibly using different internal circuitry and different manufacturing processes, this parameter variability can be expected to become even greater. Derating helps to compensate for this type of "strength" variability.

Part "Strength" is directly related to specific but different parameters for different generic part types. The "strength" of capacitors is primarily a function of the applied voltage at a given temperature. For most solid state electronic parts the "strength" is simultaneously related to three different parameters, junction temperature, voltage, and current. Therefore, we may need to look at more than one parameter for a given part and at a variety of different parameters for different generic part types.

An additional reason for derating is the fact that critical part parameters are not completely stable throughout the part's life. Derating can make quantitative allowances for a part's functional degradation. While many part parameter changes are predictable as a function of time, temperature, etc., unfortunately other part parameter changes are random and hence are not predictable. Again, derating helps to compensate for this type of variability.

Derating as Much an Art as Science

In essence, each specific part derating guideline is based upon an actual or implied inflection point in a stress parameter versus the failure rate curve for that part. That is, beyond this inflection point the failure rate of the part increases much more rapidly as that parameter is increased. Given the difficulty in accurately determining an inflection point in a curve and all of the other variables present, derating emerges as much an art as it is a science. The art lies in selecting the "right" amount of derating. Insufficient derating is obviously undesirable. On the other hand, excessive derating would likely either add more parts or require higher rated parts in the design and actually decrease overall system reliability or increase the product cost.

Thus, although there is general agreement on the need to derate, not all published "Derating Guidelines" and certainly not all derating practitioners would come to the same conclusions regarding the optimum degree of derating for a specific parameter for specific part in a specific design application. Hence, we should use the term "Derating Guidelines" and not "Derating Rules." Furthermore, derating as an art means that experience is essential for the derating practitioner. The goal of derating, is to enhance the reliability and stability of a given design and it represents a crucial step in the design process for every part application.

Stress/Strength Interference

As previously stated, a generic part's strength varies within a lot, from lot to lot, and from manufacturer to manufacturer. Strength is a random variable that can be represented by a statistical distribution. Likewise, the stress applied to a part in a given application may also be considered random, changing with temperature, vibration, mechanical shock, electrical transients, radiation and other environmental factors. These stresses can also be represented by a statistical distribution.

Figure 1 illustrates the relationship between the strength of a part and the applied stress.

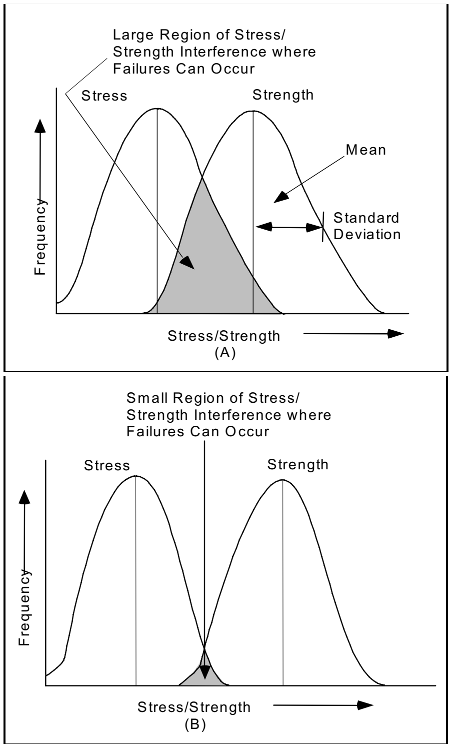

Figure 1. Part Stress vs. Part Strength Relationship

Failure is likely to occur whenever the applied stress exceeds the strength of the part. This is represented by the interference (the overlap) between the two distributions, the shaded area on the two subfigures. A more detailed explanation of interference theory may be found in the RAC publication "Mechanical Applications in Reliability Engineering" (Reference 3).

This interference can be reduced using one of two obvious ways: 1) move the distributions farther apart, i.e., increase the strength of the part and 2) narrow the distributions, i.e., reduce the part strength variability. Considering these two approaches, we can see that, other things being equal, a part whose strength parameter variability is tightly controlled (e.g., a part produced in large quantities in continuous production for a long time with good statistical process controls (SPC)) will require less derating than a part that exhibits significant strength parameter variability (e.g., a part intermittently produced in small batches with minimum or no SPC).

The principle sources of variation for a specific generic part are a function of the part type as shown in Table 1.

Application of Derating Factors for Electronics

Derating guidelines (other than temperature) are typically stress ratios expressed as a percentage value. 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 rated operating temperature.

To properly derate a specific part, a significant amount of detailed part construction information may be required. For example there are many different types of capacitors; Paper Film, Plastic Film, Mica, Glass, Ceramic, Tantalum Electrolytic, and Aluminum Electrolytic just to name a few. They are typically used in different types of applications and do not all exhibit the same failure modes and mechanisms. Individual construction differences can be significant. For example, the nature of one of the primary failure mechanism in aluminum electrolytic capacitors (i.e., breakdown of the dielectric by the electrolyte in the absence of applied voltage) is such that voltage derating by itself does not enhance the reliability of these parts. Similar technology difference examples could be given for many generic part types, especially solid state devices.

Derating guidelines can take a variety of forms. They are often published with different derating values for different environments. For example, the older military documents (References 6 and 7) typically gave three different sets of values in columns; one (the most severe derating) for a "Space" environment, a second (less severe) for "Aircraft" and a third (least severe) for "Ground." A more current military approach "Part Requirement & Application Guide" (SD-18) (Reference 1) still uses three columns but identifies the columns as "Protected", "Normal" and "Severe" environments. RAC derating guidelines (see Reference 2 & 4) give two environment columns "Severe" and "Benign." The whole purpose of these multiple column approaches is to provide additional safety margins in critical applications or when the parts are subjected to extreme environmental conditions.

Transient conditions should also be taken into account. The derating analysis will not necessarily 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 also be examined and the probability of worst case occurrence be further investigated.

Table 1. Part Type vs. Principal Sources of Variation

Source of Variation	Part Type						
	Transistor	Diode	Integrated Circuit	Resistor	Capacitor	Inductor	Relay
Temperature	X	X	X	X	X	X	X
Aging	X			X	X		
Radiation	X	X	X				
Vibration/Shock				X	X	X	X
Humidity				X	X		
Life				X	X		
Altitude				X	X		
Electrical Stress	X	X			X		

To determine the derating conditions that should be applied to a specific product design, an analytical approximation, extracted from Reference 4, is included as Table 2. Table 2 has a set of factors that can be scored based on the challenge that the product design is expected to survive. For scores of eight or greater, the severe derating standards should be considered. Lesser scores indicate that the benign derating factors are appropriate.

Table 2. Part Derating Level Determination

Factors		Score
Reliability Challenge	For proven design, achievable with commercial parts/circuits	1
	For high reliability requirements, special design features needed	2
	For new design challenging the state-of-the-art, new concept	3
Repair	For easily accessible, quickly and economically repaired products	1
	For high repair cost, limited access, high skill levels required, very low downtimes allowable	2
	For non-accessible repair, or economically unjustifiable repairs	3
Safety	For routine safety program, no expected problems	1
	For potential system or equipment high cost damage	2
	For potential jeopardizing of life of personnel	3
Size, Weight	For no significant design limitation, commercial practices	1
	For special design features needed, difficult requirements	2
	For new concepts needed, severe design limitation	3
Life Cycle	For economical repairs, no unusual spare part costs expected	1
	For potentially high repair cost or unique cost spares	2
	For systems that may require complete substitution	3
Select score for each factor, sum the scores, and determine derating level or parameter.		
Derating Level	**Total Score**	
Severe	8-15	
Benign	For Less	

Examples of Part Derating Factors

A few examples of specific part derating factors, extracted from References 2 and 4, are shown in Table 3. For a more comprehensive listing of specific part derating factors go to the RAC Toolbox Derating Tool (Reference 2) at <http://rac.alionscience.com/pdf/PartDeratingParameters.pdf>. A more thorough in-depth treatment of the topic is available in Reference 4, the RAC publication "Electronic Derating for Optimum Performance (D-Rate). This reference includes technology differences, failure modes and mechanisms, general derating guidelines, construction factors and application information for all of the various different generic part types.

Table 3. Silicon and GaAs Transistor Derating Factors

Type	Parameter	Derating Factor	
		Severe	**Benign**
Bipolar Junction	Power Dissipation (P_D)	90%	<100%
	Voltage (V)	70%	80%
	Junction Temperature (T_J)	95°C	115°C
Field-Effect, Silicon	Power Dissipation (P_D)	90%	<100%
	Breakdown Voltage (V_{BR})	90%	<100%
	Junction Temperature (T_J)	95°C	115°C
Field-Effect, GaAs	Power Dissipation (P_D)	90%	<100%
	Channel Temperature (T_{CH})	105°C	125°C

Summary and Conclusions

Derating of electronic and electromechanical components to reduce the stresses applied can be one of the most important design related actions that a manufacturer of a product can take. Every component has limitations on its performance capabilities and extreme stresses reduce this capability. If the product has a defect, even a minor one, the extra applied stresses will reduce the time until degraded performance or failure occurs. By decreasing mechanical, thermal, electrical and other environmental stresses and increasing component strengths, the possibility of degradation or catastrophic failure is lessened. Because all the operating characteristics of components cannot be guaranteed by the component manufacturer, it is good policy to derate generously to provide adequate margin of safety and reduce actual component failure rates.

What About Mechanical/Structural Parts?

One of the major differences between electronic parts and mechanical parts is analogous to the difference between purchasing a suit "off-the-rack" versus one that is "tailor-made" for you. Electronic parts can be considered "off-the-rack" while the mechanical parts are more frequently "tailor-made." Although the principle of derating is equally applicable to mechanical parts, the methodology for doing it is not nearly as straightforward as it is for electronic parts. The primary reason is that most parameters for electronic parts are sufficiently well characterized in the manufacturer's literature such that the part can be properly applied, in a variety of very different design applications, based solely on that data; i.e., "One-Size-Fits-All."

This "One-Size-Fits-All" is not generally the case for mechanical parts. Mechanical parts (other than simple fasteners, nuts and bolts, etc.) tend to be much more application-unique. They typically are designed specifically for a given design application and any specific part parameter data is not generally directly transferable to a different design application.

A second major difference between electronic parts and mechanical parts is the essential need to address the wearout of mechanical parts. Typically the life of electronic parts is much greater than the life of the equipment into which it is installed (e.g., a fifty-year part life vs. a ten-year equipment use life). Having such a long life compared to the system life is not necessarily the case for mechanical parts due to wearout. Because of wearout concerns and the application-unique characteristics of mechanical parts, much of the design effort for mechanical parts is devoted to the establishment of the stress parameter versus failure rate (or life) curves.

Although there are some general rules for mechanical parts application, the approach is typically referred to as applying a "safety factor" rather than a "derating guideline." Mechanical/structural derating is much more wearout and application sensitive; hence the results of the analysis are characteristically unique and typically are limited to only a given design application.

References

1. "Part Requirement & Application Guide" SD-18, March 2001 <http://pats.crane.navy.mil/component/applications. htm>.

2. "Part Derating Parameters," RAC Toolbox Tool, 2001, <http://rac.alionscience.com/pdf/PartDeratingParameters.pdf>.
3. "Mechanical Applications in Reliability Engineering," RAC Publication NPS, 1993.
4. "Electronic Derating for Optimum Performance," RAC publication D-Rate, 1999.
5. "Parts Application and Reliability Information Manual for Navy Electronic Equipment," TE-000-AB-GTP-010, Rev. 2, Naval Sea Systems, Crane IN.
6. "MIL-STD-975 NASA Standard Parts Derating."
7. "AFSC Pamphlet 800-27 Parts Derating Guidelines," 1983.

About the Author

Norman B. Fuqua is a Senior Engineer with Alion Science and Technology. He has 44 years of varied experience in the field of dependability, reliability, and maintainability and has applied these principles to a variety of military, space, and commercial programs. At Alion Science and Technology, and its predecessor IIT Research Institute (IITRI), he has been responsible for reliability and maintainability training and for the planning and implementation of various dependability, reliability, and maintainability study programs.

Mr. Fuqua developed unique distance learning Web-based and Windows™-based computer-aided reliability training courses. He is the developer and lead instructor for the Reliability Analysis Center's (RAC) popular Electronic Design Reliability Training Course. This three-day course has been presented over 200 times to some 7,000 students in the US, England, Denmark, Norway, Sweden, Finland, Germany, Israel, Canada, Australia, Brazil, and India. Audiences have included space, military, industrial, and commercial clients.

He was also the lead developer and instructor for a two-day Dependability Training Course for an Automotive Supplier and a three-day Robust Circuit Design Training Course. These courses enable mechanical and electronic design engineers and reliability engineers to utilize advanced software-based tools in producing designs that exhibit minimum sensitivity to both internal and external variations.

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He is the author of a number of technical papers, twenty RAC publications and a reliability college textbook published by Marcel Dekker Inc.

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