Derating

Components can be treated in such a way as to enhance their life expectancy. ‘Derating’ is the name normally given to operating a component well inside its normal operating limits, in order to reduce the rate at which the component deteriorates. That derating is a practical means of reducing failures is supported by much published literature.

Conceptually, it is easy to see that, whilst the component may be specified to operate at high voltage and high temperature, applying those conditions simultaneously would probably be worse than applying either one or the other. Also that, if a component has a voltage rating such that it will start to fail at, say, 130% of maximum rating, reducing the voltage applied to substantially below the maximum permitted should reduce distress, and by doing so extend the life.

Also given that reactions are known to proceed at higher speeds at higher temperatures (an insight originally shared by Arrhenius), one would predict reduced degradation, and hence extended life, by running a component at lower than its maximum category temperature.

$$T_J = T_A + P_D \times \theta_{JA}$$

where T_J = die junction temperature
T_A = ambient temperature in the vicinity of the device
P_D = total power dissipation (W)
θ_{JA} = thermal resistance junction-to-ambient ($°C.W^{-1}$)

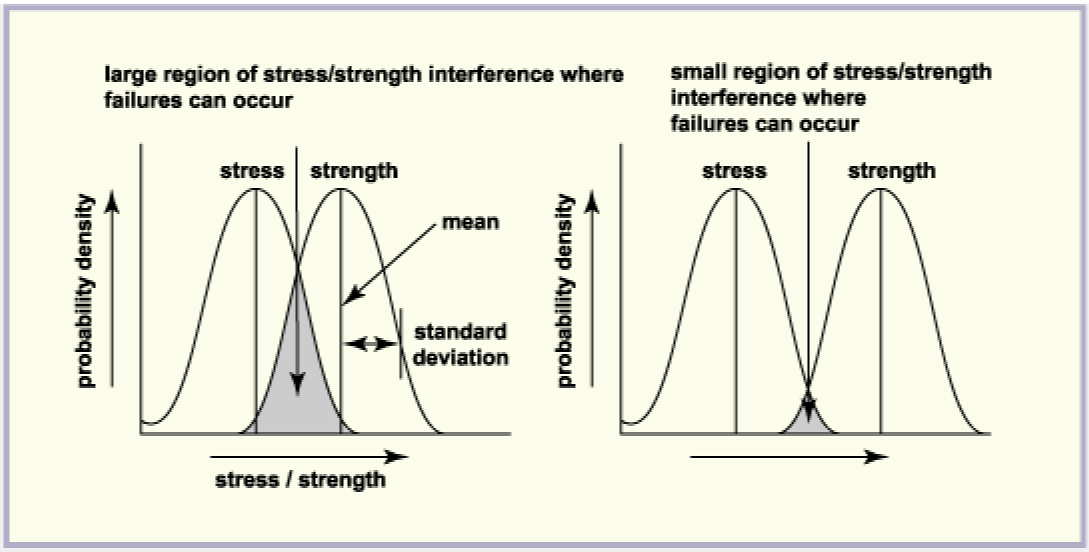
Manufacturers such an National Semiconductor will sometimes point out that there is a strong relationship between junction temperature and failure rate, frequently modelling this as an Arrhenius curve, and predicting perhaps a 10:1 increase in failure rate for a rise in junction temperature from 130°C to 160°C, based on a 1eV activation energy.

There will be other evidence of derating, for example high-current devices may be recommended a ‘soft start’ circuit, in order to prevent damage from inrush current. When we did our own search, we found an interesting comment from Phillips Semiconductors that “Exposure to limiting values for extended periods may affect device reliability”.

You may also have come across references to MIL-HDBK-217F, which predicts failure rates for different devices based on the severity of the application, generally using the Arrhenius model. At the same time you may have read material that leaves you far from convinced that the MIL-HDBK-217F model is fully applicable to temperature, and may well not apply at all to other sources of stress.

Lest you think that derating as a practice is not supported by theory, it is worth looking at an alternative view, which strongly supports at least a modicum of derating. This approach is explained in the Reliability Analysis Center’s *Mechanical Applications in Reliability Engineering*. This refers to the ‘strength’ of a part, which is a random variable that can be represented by statistical distribution. Likewise, the stress applied to a part is random, changing the temperature, vibration, transients, shock and other environmental factors, and able also to be represented by a statistical distribution.

Figure 1: Relationship between part strength and part stress



after Reliability Analysis Center (RAC)

Figure 1 plots these two probability densities assuming a normal (Gaussian) distribution for both stress and strength – even though such a distribution is probably not totally realistic, the comments still apply. The classical approach has been to select every part to have enough ‘strength’ to handle the worse case stress conditions, thereby reducing to a minimum the intersection (shaded) areas of the graphs where there is a slight chance that the stress applied to a part will exceed its strength. More recent approaches take into account the probabilistic nature of this ‘interference’ between the two distributions.

Using this insight, the four basic strategies for stress derating can be seen to be:

- to increase the average strength
- to decrease the average stress
- to decrease the stress variation
- to decrease the strength variation.

All of these are possible, but variations are more difficult to control.

The purpose of derating is to protect against these variations, preventing small changes in operating characteristics (usually temperature) from creating large increases in failure rate. Given that the simplest approach to increase average strength, this will normally be done by procuring a more capable component. For example, choosing a 100V capacitor rather than the 63V type for operation on a 60V line.

The amount of derating that is needed will depend on how well the designer can predict the variation in operating parameters, both before the part is assembled and during the operating environment over the lifetime of the part. Because the sources of variation are extremely difficult to quantify, engineering estimates in past experience are often used to estimate the derating level needed.

Not every factor will affect every type of component – Table 1 shows the most significant causes of variation for the performance of different types of component.

Table 1: Principal sources of variation for different types of component after Reliability Analysis Center (RAC)

	transistor	diode	IC	resistor	capacitor	inductor	relay
temperature	X	X	X	X	X	X	X
aging	X			X	X		X
radiation	X	X	X				
vibration/shock				X	X	X	X
humidity				X	X		
life				X	X		
electrical stress	X	X			X		

X: Significantly affected by environment

The principal practical question is to determine what are reasonable derating parameters, and information founded on hard evidence is hard to obtain. However, an indication of appropriate part derating parameters has been published by RAC, and part of this is reproduced as Table 2.

Table 2: Selected suggested part derating parameters after Reliability Analysis Center (RAC)

Part type	Derating parameters	Severe	Benign
Aluminium electrolytic caps	Voltage (% max rated)	70%	80%
	Temperature (°C)	T_{max}−20°C	T_{max}−20°C
Ceramic capacitors	Voltage (% max rated)	60%	70%
	Temperature (°C)	T_{max}−10°C	T_{max}−10°C
Solid tantalum capacitors	Voltage (% max rated)	70%	80%
	Temperature (°C)	T_{max}−20°C	T_{max}−20°C
	Reverse voltage (% max fwd)	2%	2%

Signal diodes	Forward current (% max rated)	90%	<100%
	Reverse voltage (% max rated)	70%	80%
	Max. junction temperature	95°C	115°C
Chip resistors	Power dissipation(% max rated)	50%	70%
Digital MOS and bipolar ICs	Fanout (% max rated)	90%	<100%
	Frequency (% max rated)	90%	<100%
	Output current (% max rated)	90%	<100%
	Max. junction temperature	95°C	115°C
Linear MOS and bipolar ICs	Frequency (% max rated)	90%	<100%
	Output current (% max rated)	90%	<100%
	Max. junction temperature	95°C	115°C
General purpose relays	Contact current (Continuous % max rated)	varies with load type:	
		75% resistive 75% capacitive 40% inductive 20% motor 10% fil. lamp	90% resistive 90% capacitive 75% inductive 30% motor 20% fil. lamp
	Contact power (% max rated)	50%	70%
	Temperature (°C)	T_{max}−20°C	T_{max}−20°C

Note that the level of derating recommended for a severe environment is greater than for a benign environmental, and that the maximum temperatures are also generally lower. There is some variation with device type, but many of the entries are quite generic. Also note that the list of parts contains mechanical components, and that these are often substantially different from electronic parts: a good example is of the general purpose relay, where the derating recommended is strongly dependent on the type of load.

Most of the discussion has centred on catastrophic failures, so it is worth being reminded that system failures are sometimes caused by parametric drift. Designers are recommended to try and make circuits as tolerant as possible to variations in part parameters. Whilst part data sheets indicate the expected level of parametric drift during environmental exposure, individual parts will vary much more. This means that, unless the design is sufficiently tolerant of drift, the product may not function properly, even though no catastrophic part failure has occurred.

A caveat

Derating is not always good news for the overall system. For example, using a component with a higher rating may mean using a larger case, creating space and weight problems. There may also be implications for cost. As with all design, there will be a trade-off between derating as much as possible and being able to meet manufacturing and marketing objectives.

Nor should it be assumed that working at low voltages is necessarily beneficial. For example, devices with contacts may give poor ‘dry circuit’ performance, and low voltage failures are also experienced with various types of capacitors. Although capacitors go short-circuit and connectors and switches become noisy or open-circuit, the source of the problem is that insufficient energy is available to clear the fault.

Source: http://www.ami.ac.uk/courses/topics/0190_drat/index.html