

Chapter 2

Generic Stress Factors and De-rating

Abstract The data sheets of components specify maximum ratings and electrical characteristics. The parameters of maximum ratings are the reliability-related stress factors of electronic components. The generic stress factors, ambient temperature, surface temperature, and junction temperature that are common to most components are explained with examples. The basics of de-rating, applying de-rating for stress factors, and thermal resistance are also explained.

2.1 Introduction

Components are the basic elements for developing electronic equipment, and the data sheets of manufacturers are used for selecting the components. The data sheets specify maximum ratings and electrical characteristics for components. The parameters of maximum ratings are the reliability-related stress factors. Examples of stress factors are rated voltage, power dissipation, maximum junction temperature, etc. Exceeding the maximum values of the stress factors reduces the reliability of components. The reliability technique, de-rating, is applied for stress factors in the selection of components to ensure that the operating stress levels of the components are within their maximum ratings.

The list of stress factors for the categories of electronic components is presented in Chap. 3. The generic stress factors that are applicable to most components and the basics of de-rating are explained with examples. Thermal resistance is not a stress factor but it is also explained as it is used for computing the junction temperature of semiconductor devices.

2.2 Ambient Temperature

Ambient temperature (T_A) of a component is the temperature of air in the vicinity of the component. The internal ambient temperature of components is usually higher than the external ambient temperature of equipment due to heat dissipation

in the equipment. It is one of the critical inputs for selecting electronic components. Three examples are provided for measuring the internal ambient temperature of components.

Example-1:

Assume that the power dissipation of an assembled PCB is low and the temperature rise is negligible, i.e., less than 5 °C. The surface temperature of PCB is the ambient temperature for the components of the PCB.

Example-2:

The surface temperature of the metal enclosure of plug-in module is the ambient temperature for the components mounted on the PCB of the module.

Example-3:

Assume a transistor is mounted in the vicinity of a heat dissipating component such as wire-wound resistor. The surface temperature of the wire-wound resistor is approximately the ambient temperature for the transistor.

2.3 Surface Temperature

Surface temperature is specified for resistors and it is the temperature at the external area of the resistors. Case temperature instead of surface temperature is used for transistors, packaged in metal cases such as TO3 (Transistor Outline-3). Case temperature is also relevant for ceramic and plastic encapsulated ICs. The surfaces of components are probed by thermocouples to measure the highest temperature. The surface or case temperature of components is related to the power dissipation in the components.

2.4 Thermal Resistance

The electrical resistance of a resistor is given by the ratio of voltage gradient between the terminals of the resistor to the current flowing through the resistor. Thermal resistance is analogous to electrical resistance. Temperature gradient exists between two points in thermal conduction path. Thermal resistance is the ratio of temperature gradient to the power dissipation of heat source. An example is provided for better understanding.

A power transistor with a heat sink is shown in Fig. 2.1. Heat is generated by power dissipation in the transistor. Conduction is the primary means of heat

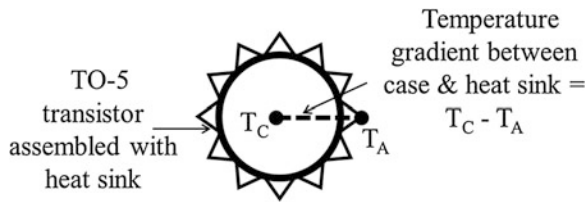


Fig. 2.1 Temperature gradient in power transistor

dissipation from the transistor to ambient, and the path of conduction is through the heat sink. Temperature gradient exists in the thermal conduction path between the case of the transistor and the heat sink and it is shown in Fig. 2.1. Assume the following:

P_D : Power dissipated by the transistor in watts

T_C : Case temperature of the transistor

T_A : Temperature at the fins of the heat sink, i.e., ambient temperature

Thermal resistance of the heat sink, $(\theta_{c-a}) = (T_C - T_A)/P_D$

The unit of thermal resistance is $^{\circ}\text{C}/\text{W}$. Using heat sinks having lower thermal resistance reduces the case temperature of the power transistor. Increasing dimensions or the number of fins or using better material reduces the thermal resistance of the heat sink.

2.5 Junction Temperature

Power dissipation in semiconductor devices increases the operating junction temperatures of the devices. The heat generated at the junction of semiconductor devices is dissipated to ambient thorough the case and leads of the devices. The construction of the devices is such that the heat at the junctions is conducted through conducting epoxy, lead frame, etc., before reaching the case or package of the devices. The conduction path results in temperature gradient between the junction and case of the devices. The temperature gradient is proportional to power dissipation and the ratio is specified as thermal resistance ($^{\circ}\text{C}/\text{W}$) between junction and the case (θ_{j-c}) of semiconductor devices by manufacturers. Operating junction temperature is one of the critical parameters of semiconductor devices as it decides the reliability of the devices. Maximum junction temperature for semiconductor devices should never be exceeded in the application of the devices in circuits. θ_{j-c} is used for computing the operating junction temperature of the devices in circuits.

2.5.1 Computing Junction Temperature

The steps in computing the operating junction temperature of a semiconductor device are:

- (i) Determine the power dissipation (P_D)
- (ii) Estimate or measure the case temperature (T_C)
- (iii) Obtain θ_{j-c} from the data sheet
- (iv) Compute operating junction temperature:

$$T_j = T_C + \theta_{j-c} * P_D$$

Heat sink might be used for semiconductor devices to reduce operating junction temperature. The thermal resistance of the heat sink and the temperature of the heat sink (T_A) are used for computing the junction temperature.

Junction temperature, $T_j = T_A + (\theta_{j-c} + \theta_{c-a})P_D$

Data sheets might specify thermal resistance from junction to ambient, θ_{j-a} , for some devices. Operating junction temperature of the devices is computed from ambient temperature.

Junction temperature, $T_j = T_A + \theta_{j-a} * P_D$

2.6 Basics of De-rating

De-rating is the ratio of operating stress level to the rating (strength) of component. Components with adequate strength should be selected to withstand the estimated operating stress levels. Consider the selection of a resistor. Power dissipation is one of the stress factors for a resistor. Let the estimated power dissipation, i.e., the operating stress level of the resistor in a circuit be 0.47 W. A resistor with 1 W rating (adequate strength) should be selected although a resistor with 0.5 W rating (inadequate strength) is available. De-rating is usually expressed in percentage. The de-rating level for the resistor is $[100*(1 - 0.47 \text{ W})/1 \text{ W}]$, i.e., 53 %. It is quite possible that the stress levels of some components could not be assessed while selecting components. In such cases, operating stress levels on the components are measured on the proto-models of equipment as explained in Chap. 5 and the selection of the components are reviewed. De-rating is applicable for both electrical and thermal ratings of components.

2.6.1 Need for De-rating

Electronic components fail during design, manufacturing, and field usage of equipment for various reasons. The nature of the failures of components could be classified as either mechanical or chemical [1]. The coil ends of electromagnetic

relays are soldered internally to the terminals of the relays. The snapping of the coil ends from the terminals under mechanical shock impacts is an example of mechanical failure. Reduction in the gain of a power amplifier chip is an example of chemical failure, caused by the chemical reaction on the die of the chip.

As per Arrhenius model, the rate of chemical reaction increases with temperature and it doubles approximately with every 10 °C increase in temperature [2]. Ambient temperature and electrical stresses increase the operating temperature of components. Applying de-rating for the stress factors of components reduces the operating temperature of components thereby reducing the failure rate of components considerably.

2.6.2 Examples of De-rating

De-rating for the stress factors except power dissipation of components could be applied directly as shown in the examples below. De-rating for power dissipation is explained in Sect. 2.6.2.1.

Example-1:

Absolute maximum junction temperature for transistor: 150 °C max.

De-rating level: 20 %

Circuit design limits operating junction temperature to 120 °C.

Example-2:

Rated voltage of chip ceramic capacitor: 50 V DC max

De-rating level: 10 %

Circuit design limits operating voltage to 45 V DC.

2.6.2.1 De-rating for Power Dissipation

Maximum rated power dissipation is normally specified at 25 °C case or ambient temperature for semi-conductor devices and at 70 °C ambient temperature for resistors. Beyond the standardized temperature of rating, the rated power of the components decreases. Power rating versus temperature graphs for a semiconductor device and a resistor are shown in Fig. 2.2a, b respectively. Manufacturers refer the graphs as de-rating or re-rating graphs. As the graphs indicate the power rating of components with temperature, it is appropriate to refer the graphs as re-rating graphs.

Power rating at the operating temperature of components is computed from the re-rating graphs and de-rating is applied for the computed power rating. The computations of power rating and de-rating the rated power are explained for a transistor. The procedure is applicable for resistors also.

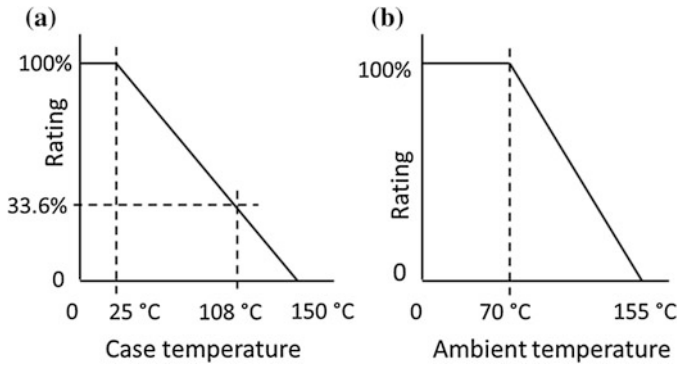


Fig. 2.2 Power rating with temperature—examples, **a** transistor rating **b** resistor rating

Example

The rated power of a transistor is 30 W at 25 °C case temperature. The power re-rating with temperature, shown in Fig. 2.2a is specified by the manufacturer of the transistor. Compute the power handling capacity of the transistor with 20 % de-rating level at 108 °C case temperature.

Solution

Rated power of transistor at 25 °C case temperature: 30 W

Operating case temperature of the transistor: 108 °C

Rated power of the transistor at 108 °C from Fig. 2.2a = 33 % of 30 W = 10 W

De-rating level: 20 %

Power handling capacity at 108 °C = 10 W – (20 % of 10 W) = 8 W

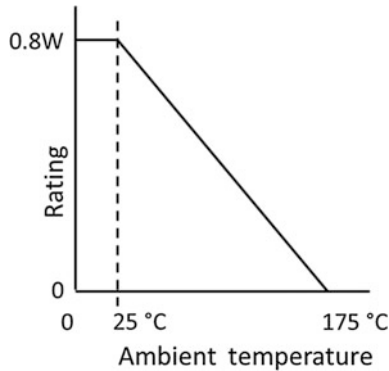
A linear equation in the form, $y = m * x + c$, could be fitted for the re-rating graphs for determining rated power with temperature, where m is the slope of the straight line characteristic.

Assessment Exercises

1. Say True or False:

- (i) De-rating means that applied stress should not exceed strength.
- (ii) The terms, de-rating and re-rating, mean the same.
- (iii) Temperature gradient between junction and case of transistor increases with power dissipation in the transistor.
- (iv) Junction temperature and case temperature of a transistor are equal if thermal resistance between junction and case is zero.

- (v) Thermal resistance between junction and case of transistor increases with power dissipation in the transistor.
2. A wire-wound resistor, embedded in metal case, is dissipating 18 W in a module. The operating ambient temperature of the resistor is 55 °C. The thermal resistance between the surface of the resistor and the metal case is 1.2 °C/W and that between the metal case and ambient is 5.8 °C/W. Compute the surface temperature of the resistor.
If the maximum surface temperature of the resistor is 200 °C, does the application satisfy the de-rating level of 10 %?
3. A low power transistor in TO-5 case is mounted in a PCB. The absolute maximum ratings and thermal resistance of the transistor are:
Power dissipation at $T_A = 25\text{ °C}$: 0.8 W
Junction temperature, $T_{j-\text{max}}$: 175 °C.
Thermal resistance, junction-ambient (θ_{j-a}): 190 °C/W.
The power rating curve with ambient temperature is shown below.



Compute the maximum power that could be dissipated by the transistor with 15 % de-rating assuming the internal operating ambient temperature of the PCB is 87 °C.

References

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