

6 Derating Concepts and Practical Methods

6.1 Introduction

Figure 6.1.1 shows the general failure rate vs. life curve of semiconductor devices.

The failure periods for equipment can be broadly classified into the three areas shown in this diagram. They are called the early failure period, the random failure period and the wear-out failure period. Each period is defined as follows:

Early failure period: The failure rate during this period decreases with time. Most failures are attributable to non-conformity to design, defects in or non-conformity with specified raw materials, processing or assembly, or incompatibility with the operating environment.

Random failure period: The failure rate during this period is not dependent on time. Failures occur randomly at intervals and are attributable to device intolerance to circuit conditions (insufficient margins), ion-induced variations in device characteristics, flaws and dust.

Wear-out failure period: The failure rate during this period increases with time. Failures are attributable to fatigue from long-term usage, mechanical wear or chemical changes, and deterioration in the product.

When specifying the electrical components to be used in the circuitry for a particular piece of equipment, choose devices which will not enter their wear-out failure period until the useful lifetime of the equipment has expired.

Failure rate curves vary with environmental conditions and other factors related to the product as shown in Figure 6.1.2. In order to improve equipment reliability, designers should try to reduce the failure rate from that shown by the solid line to that shown by the dotted line in the diagram.

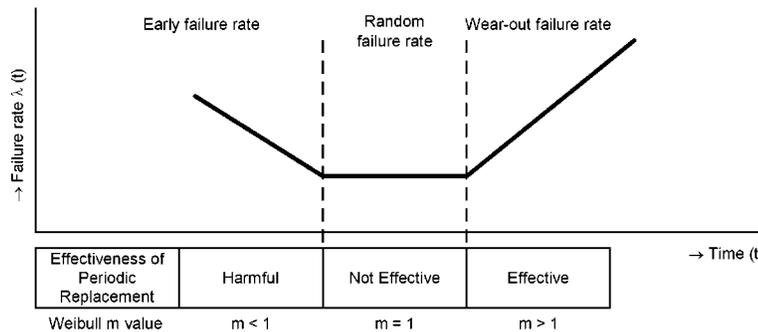


Figure 6.1.1 Lifetime curve

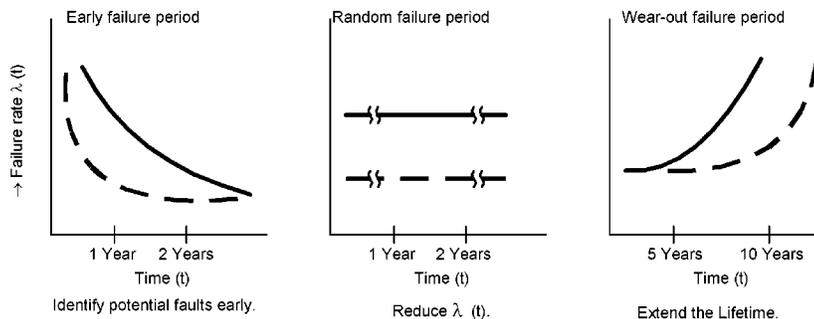


Figure 6.1.2 Methods for improving reliability

6.2 Definition of Failure Rate

Failure rate is defined as the ratio of faults caused by equipment or components to unit time. It is an approximation of the reliability that can be expected for a particular component or piece of equipment.

Failure rate is normally expressed in units of FIT (failure in time). One FIT represents 1×10^{-9} failures per unit time.

The failure rate for components normally refers to failures during the random failure period. In this case the concept of failure rate with respect to time may be thought of as the product of time and failure rate. For example, if 100 units of a 100-FIT component are used for 10,000 hours, 0.1 units will fail.

However, there are many methods for calculating failure rate, and the values listed in the catalogs published by component manufacturers do not necessarily correspond to one another, since each manufacturer calculates failure rates under different conditions. This makes comparison difficult. These values can thus only be used as an approximate guide.

Consequently, the most practical method of estimating component failure rates is to use actual field data.

6.3 Estimating Equipment Failure Rates

The following description explains how to determine equipment failure rates from component failure rates, and component failure rates from actual equipment records.

Using the manufacturer-specified failure rates for the components, and assuming a series model in which individual failures occur independently and the failure of any one component causes the equipment to fail, the equipment failure rate is given by the sum of all component failure rates, as expressed by the following equation.

$$\lambda = K \sum_{i=1}^n \lambda_i \times n_i \dots\dots\dots 1)$$

For example, the failure rate of a piece of equipment using four kinds of component is given by

$$\lambda = K \times (\lambda_1 \times n_1 + \lambda_2 \times n_2 + \lambda_3 \times n_3 + \lambda_4 \times n_4) \text{ FIT}$$

Similarly, the MTBF for the equipment is given by

$$\text{MTBF} = 1 / \lambda$$

In this equation, K denotes a severity factor which numerically represents the severity of the environment and how it affects equipment reliability. This factor is assumed to be 1 when the equipment is used under normal temperature and humidity conditions at ground level.

Figure 6.3.1 shows the relationship between component counts and equipment MTBF for various component failure rates. The diagram shows that reducing the component failure rate is an effective means of improving the equipments, MTBF, and that if the failure rate of each component is reduced by one order of magnitude, the equipment's MTBF is increased ten-fold.

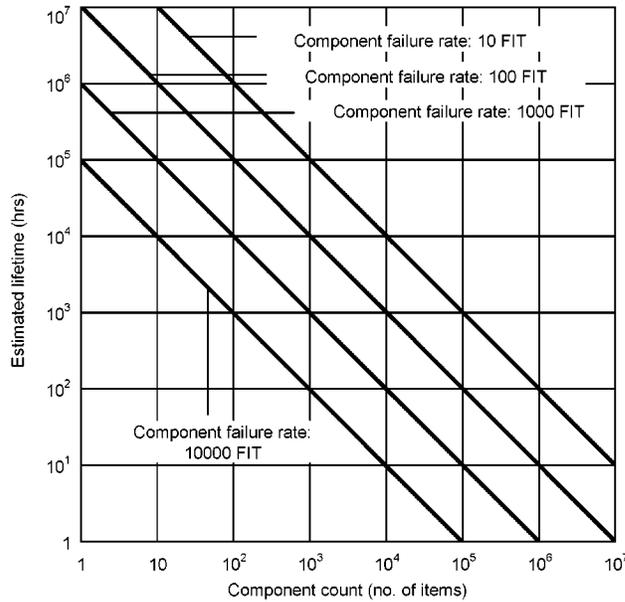


Figure 6.3.1 Relationship between component count and equipment MTBF

Table 6.3.1 Calculating component failure rate from field records

Equipment failure rates and MTBFs, and component failure rates can be obtained from equipment field records as follows.

Table 6.3.1 lists the failures for one type of equipment that occurred for each month of delivery during a six-month period. The data was collected from customer cards and service reports, and tabulated after exclusion of early failures.

Month of Delivery	Number of Units Delivered	Number of Failures	Failures Attributable to Component A
January	100	5	0
February	150	3	1
March	50	2	0
April	200	10	2
May	100	3	0
June	150	4	1
Total	750	27	4

The table also enumerates the cases where a failure in component A resulted in an equipment failure.

Assuming that the equipment operates four hours a day for 25 days each month, thus operating 100 hours per month, the MTBF of the equipment can be calculated as follows:

$$MTBF = \frac{\sum_{i=1}^n n_i \cdot t_i}{\sum_{i=1}^n m_i} \dots\dots\dots 2)$$

where n = number of months in the operating period
 n_i = number of units delivered each month
 t_i = operating time per unit of the delivered equipment
 m_i = total number of failures during the period

thus,

$$MTBF = [(100 \times 6 + 150 \times 5 + 50 \times 4 + 200 \times 3 + 100 \times 2 + 150 \times 1) / (5 + 3 + 2 + 10 + 3 + 4)] \times 100 = 9259 \text{ hours (12.8 months)}$$

Next, the failure rate for component A can be calculated using the following equation:

$$\lambda = \frac{\text{Number of failures of component}}{\text{Total operating time of component within a certain time period}}$$

Assuming that 100 units of component A are used per unit of equipment, the failure rate λ of component A is represented by the equation

$$\lambda = [(1 + 2 + 1) / (100 \times 100 \times 6 + 150 \times 100 \times 5 + 50 \times 100 \times 4 + 200 \times 100 \times 3 + 100 \times 100 \times 2 + 150 \times 100 \times 1)] \times 1 / 100 = [(4 / 250000)] \times 1 / 100 = 1.6 \times 10^{-7} = 160 \text{ FIT}$$

How this data is passed back and used in the device design and fabrication processes varies from manufacturer to manufacturer. This information forms an important part of each manufacturer's knowledge base and determines the future strategy of the manufacturer.

6.4 Derating Concepts and Their Practical Application

To extend equipment MTBFs, individual component failure rates must be reduced as described above. For semiconductor devices, failure rates are affected to a large extent by the operating environment and conditions.

For discrete semiconductor devices, operating conditions are determined solely by the equipment designer. The designer must therefore have a good understanding of the process of derating semiconductor devices to reduce failure rates. For temperature and power characteristics in particular, environmental conditions may have to be simulated by modeling.

Naturally, care must be taken to ensure that the target environmental conditions do not exceed the devices' absolute maximum ratings.

There are several known methods for estimating the failure rates of semiconductor devices, including MIL-HDBK-217E under the MIL standards and the Standard Reliability 57-1 procedure developed by Nippon Telephone and Telegraph (NTT). These methods use forecasting models based on past market data from which failure rates of semiconductor devices under specific working conditions can be determined.

Figure 6.4.1 and Figure 6.4.2 show example derating curves for Si NPN power transistors obtained from the MIL standard and the NTT procedure.

Derating curves based on NTT's Standard Reliability 57-1 procedure show that the basic failure rate can be lowered by as much as 2/3, from 70 FIT to 25 FIT, by reducing the junction temperature from 100°C to 80°C and the power by 20%. This suggests the importance of the derating process.

Note, however, that these forecasting methods classify semiconductor devices according to their use and may not necessarily be effective for a particular type of device. This is because the process stability and level of technology for actual devices vary greatly. Semiconductor manufacturers often employ their own procedures, similar to, but not as detailed as the MIL method, for determining derating curves. Such procedures are based on the manufacturer's in-house accelerated test results and the manufacturer's own market data.

Figure 6.4.3 shows a derating curve for silicon transistors based on Toshiba accelerated tests and market data.

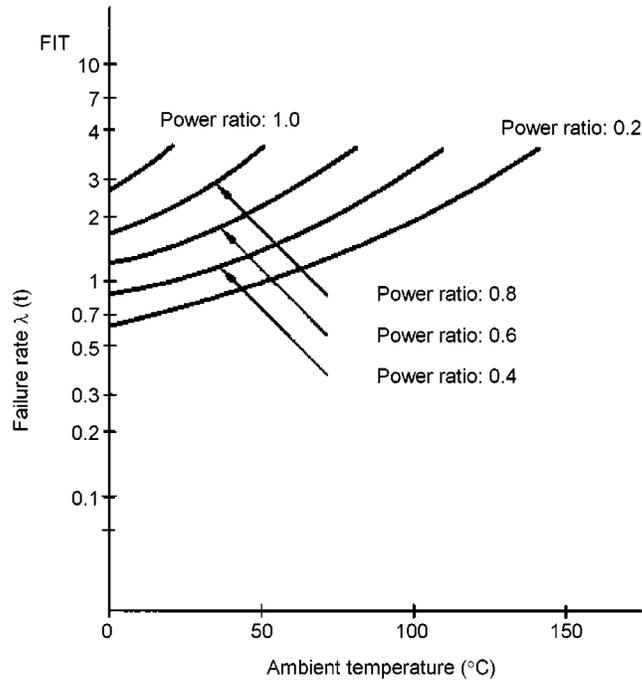


Figure 6.4.1 Derating Using MIL-HDBK-217E

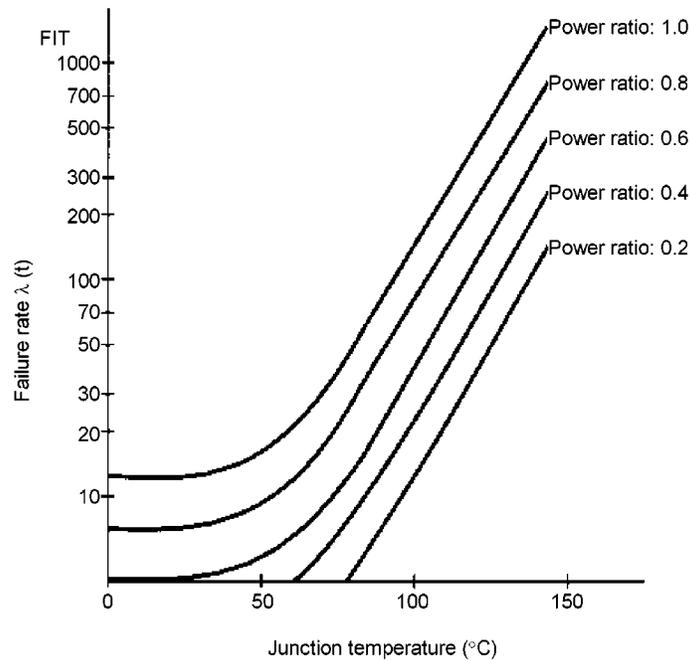


Figure 6.4.2 Derating Using NTT Standard Reliability 57-1

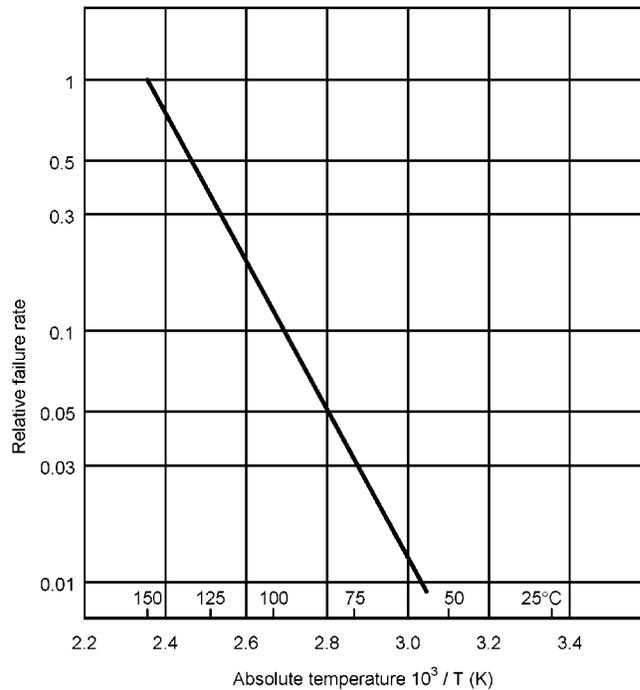


Figure 6.4.3 Derating curve for a silicon transistor

6.5 Recommended Derating

The degree of derating relative to the absolute maximum ratings greatly affects the resultant reliability. The following explanation is a guide for determining degrees of derating. Although various relevant variables are taken into account here, an examination of individual device data may be necessary before actual derating levels can be properly determined.

- Voltage: The worst-case voltage, including surges, should be 80% or less of the rated absolute maximum voltage.
- Current: The worst-case current, including surges, should be 80% or less of the rated absolute maximum current.
- Power: The worst-case power, including surges, should be 50% or less of the allowable maximum power dissipation at the maximum ambient temperature for the equipment.
- Temperature: The maximum operating junction temperature, taking into account surges, current concentration and other factors, should be 70% ~ 80% or less of the rated absolute maximum junction temperature.
- SOA: (safe operating area) The rated absolute maximum values must never be exceeded.

If an extremely high level of reliability is required, the percentages recommended above for derating can be modified as necessary.

Thus, improved equipment reliability depends largely on the reliability of the components used in the equipment. To ensure a high level of equipment reliability, therefore, designers should fully understand the failure rate characteristics of semiconductor devices and then implement the appropriate derating strategy.

Bibliography

- Calculation of MTBF and Its Interpretation, Transistor Technology, March issue (1978)
- JIS Z8115 Reliability Terminology
- MIL-HDBK-217E
- NTT S57-1

