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FAILURE-RATE AS A FUNCTION OF TIME DUE TO LOG-NORMAL LIFE DISTRIBUTION(S) OF WEAK PARTS

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Abstract—The presence of weak parts (i.e. damaged; with shorter life length expectancy) within a batch of components will give rise to a high initial failure-rate which will then decrease by time. Life tests have shown that weak parts have a more or less lognormal life distribution. This distribution has been assumed when calculating the failure-rate as a function of time as well as the influence of burn-in on the failure rate during actual use.

A calculator program has been developed that makes it easy to predict the failure-rate during normal use from data retained from life tests.

INTRODUCTION

First, one should be aware that failure-rate is nothing more than the result of calculations.

The basic information is:

(1) How many devices will fail?

(2) When will they fail? (life distribution)

If you know the life distribution(s) and the amount of devices in these, the calculation of the failure-rate is a matter of mathematics only.

Ultimately all devices will fail but for example during actual use perhaps 2% will fail. Most of these are so called "early failures" and hopefully very few belong to the wear-out population.

Life tests and failure analysis often indicate that most of the failures have an activation energy around 1 eV except for oxide defects with an activation energy of 0.3 eV.

Therefore it was concluded that a model consisting of two distributions of "early failures" and one distribution for the main part with long life should be developed.

This model should make it possible to calculate the instantaneous failure-rate as a function of time and stress.

Figure 1 helps to describe the model and shows the life distributions at two temperatures.

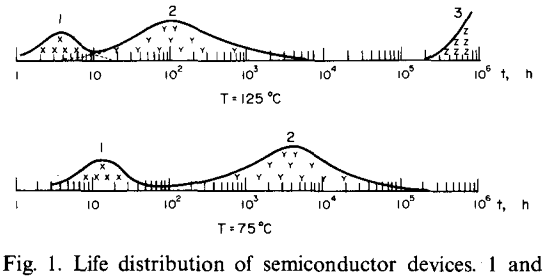

Fig. 1. Life distribution of semiconductor devices. 1 and 2 are "early failures", 3 represents the ultimate wear out (Example).

FAILURE-RATE CALCULATION

The median life times of distributions 1 and 2 must be estimated by testing and be expressed for a certain test temperature T_0 such as 125°C.

P_1 and P_2 are the parts of the total batch belonging to the distributions 1 and 2. They can be estimated by life tests as can the respective dispersions (σ).

The failure-rate due to weak distributions of P_i% can be calculated by equation (1). Ref. [3]

$$Z(t, T) = \frac{1}{t \cdot \ln 10 \cdot \sqrt{2\pi}} \cdot \frac{\sum_i \frac{P_i}{\sigma_i} \exp(-x_i^2/2)}{\sum_i P_i[1 - \phi(x_i)]} \tag{1}$$

$$x_i = \log_{10}[t/t_i(T)]/\sigma_i \tag{2}$$

$$t_i(T) = B \cdot t_i(T_0) \tag{3}$$

$$B = \exp\{11608 \cdot E_{Ai} \cdot [1/(273 + T) - 1/(273 + T_0)]\} \tag{4}$$

$$\phi(x) = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{x} \exp(-u^2/2)\, du \tag{5}$$

where

Z = failure rate in failures/h
t = time (h)
T = temperature (°C)
P_i = lot fraction of distribution i (%)
σ_i = dispersion in decades of distribution i
$t_i(T)$ = median life of distribution i at T(h)
E_{Ai} = activation energy representative for distribution i (eV).

Table 1. Input data for the model

	%	σ (decades)	E_A (eV)	$\dot{t}$ (To) Median life
Distribution 1	P_1	σ_1	E_{A1}	$\dot{t}_1$
Distribution 2	P_2	σ_2	E_{A2}	$\dot{t}_2$
Distribution 3	100-P_1-P_2	σ_3	E_{A3}	$\dot{t}_3$

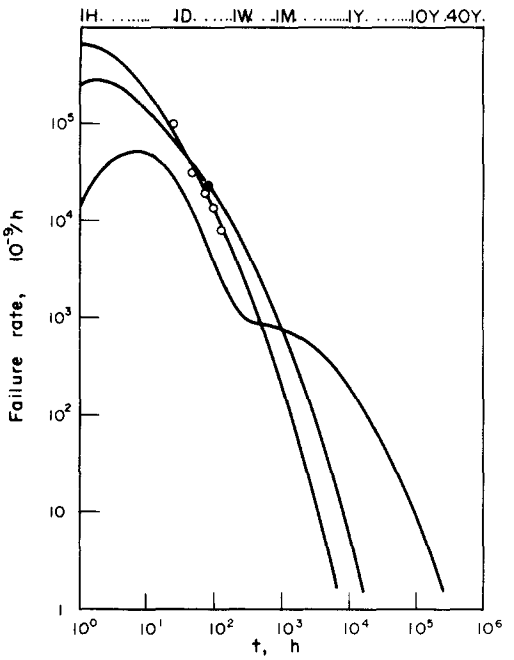

Fig. 2. Measured and predicted failure rate of TTL-circuits at 150°C, 130°C and 75°C. Input data as per Table 2. Solid lines predicted, ○ = measured at 150°C; ● = measured at 130°C.

Note that when only one distribution is used (wear out only) equation (1) simplifies to equation (6) as given by Dr F. H. Reynolds in ref [1]. (Partly rearranged)

$$Z(t) = \frac{\exp(-x^2/2)}{t \cdot \ln 10 \cdot \sqrt{2\pi} \cdot \sigma \, [1 - \phi(x)]}. \qquad (6)$$

EFFECT OF BURN-IN

Equation 1 can easily be used in order to estimate the effect of burn-in. A burn-in at T_0 for t_0 hours will be the same as $B \times t_0$ at temperature T with B from equation (4). After burn-in the failure-rate in use will start at the level given by equation (1) at $t = Bt_0$.

EXAMPLES

Some examples will illustrate the use of the model on results from life tests. The program makes it possible to easily estimate the failure-rate at different stresses including the test stress.

Figure 2 shows predicted and measured failure-rate of TTL circuits at three temperatures. Input data as in Table 2 below

Table 2. Input data for Figure 2

Distribution	% of batch	Dispersion	E_A (eV)	Median life at 150°C
1	0.2	0.5	0.3	4
2	0.8	0.75	1	24
3	99	0.7	1	10^8

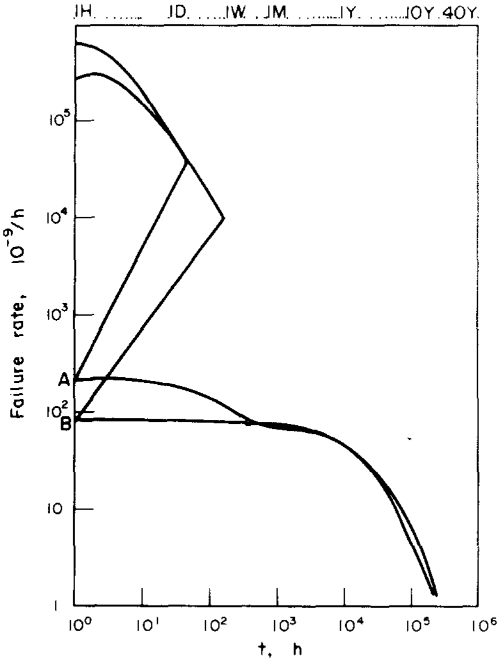

Fig. 3. The influence of burn-in at 150°C and 130°C on the failure rate in use at 75°C. Predicted as per Table 2. A: 48 h burn-in at 150°C; B: 168 h burn-in at 130°C.

Figure 3 gives the result of different forms of burn-in on the failure-rate in use. The same example as in Table 2. It may be concluded that one week at 130°C is approximately equivalent to 48 h at 150°C after the first month in use.

Figure 4 shows the predicted and measured failure-rate of a weak batch of TTL low-power devices. Input data as in Table 3 below.

Table 3. Input data for Figure 4

Distribution	% of batch	Dispersion	E_A (eV)	Median life at 160°C
1	2	0.5	0.3	5
2	10	0.9	0.6	250
3	88	0.3	1	2000

Figure 5 shows predicted and measured failure-rate of aluminium electrolytic capacitors. Input data as in Table 4 below.

Table 4. Input data for Figure 5

Distribution	% of batch	Dispersion	E_A (eV)	Median life at 40°C
1	0.06	0.9	0.8	10^4
2	99.94	0.2	1	3.5×10^5

Figure 6 shows predicted and measured failure-rate of plastic encapsulated SSI. The measured data is from Kemény (ref [2] Figure 10). Input data as in Table 5 below. In this case a temperature dependency

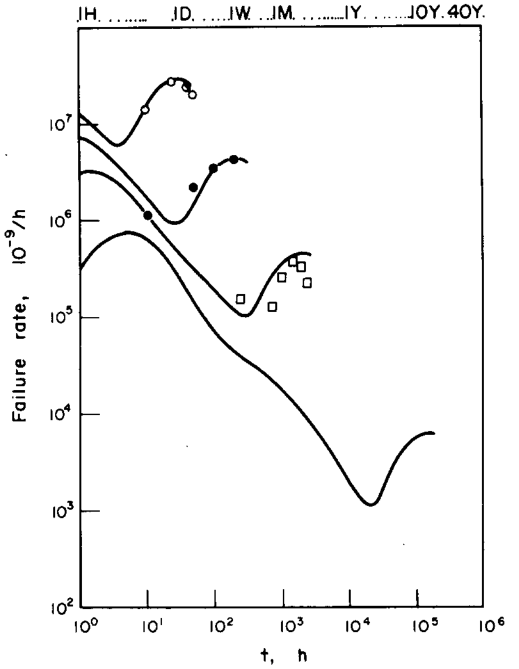

Fig. 4. Measured and predicted failure rate of a weak batch of low-power TTL. Predicted as per Table 3. ○: Measured at 240°C; ●: Measured at 200°C; □: Measured at 160°C; —: Predicted at 100°C.

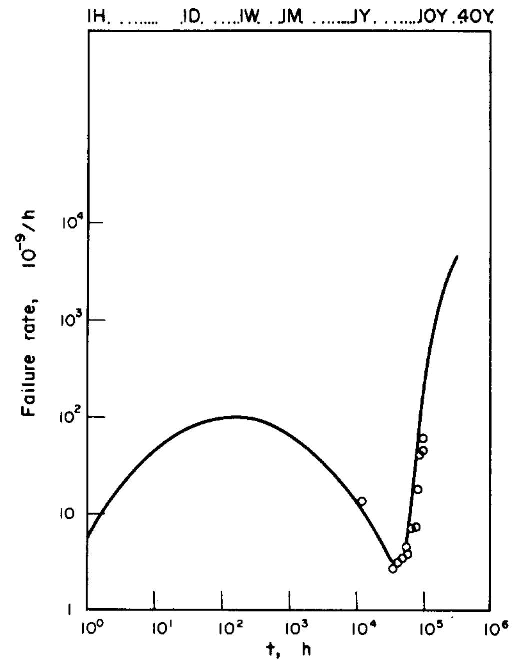

Fig. 5. Measured and predicted failure rate of aluminium electrolytic capacitors. Input data as per Table 4. ○: Measured at 40°C.

has been added to percentages P_1 and P_2. That means that the temperature both *accelerates* the mortality process and to some extent *creates* new additional weak devices by some mechanism.

$$70°\text{C} \leq T \leq 150°\ \text{C}: P(T) = P_{70}(1 + 0.03(T - 70))$$

$$T > 150°\ \text{C}: P(T) = P(150)$$

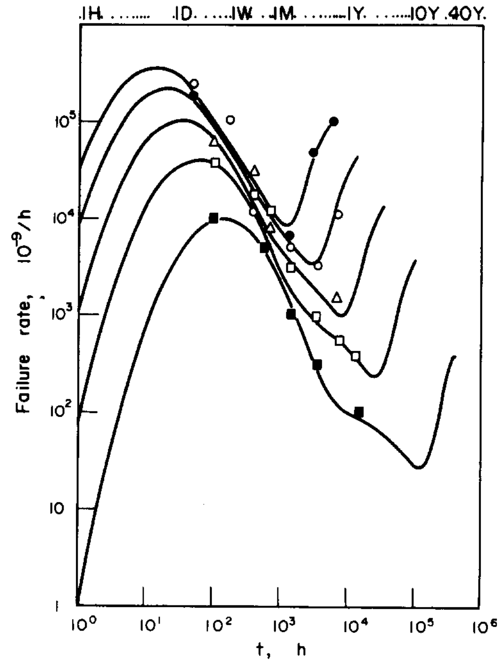

Fig. 6. Measured and predicted failure rate of plastic encapsulated TTL. Measured data according to Ref. [2]. ●: 175°C, ○: 150°C, △: 125°C, □: 100°C, ■: 70°C. Predicted as per Table 5.

Table 5. Input data for Figure 6

Distribution	% of batch at 70°C	Dispersion σ	E_A (eV)	Median life at 70°C
1	0.75	0.5	0.3	500
2	1	0.7	0.6	10^5
3	98.25	0.25	0.6	10^6

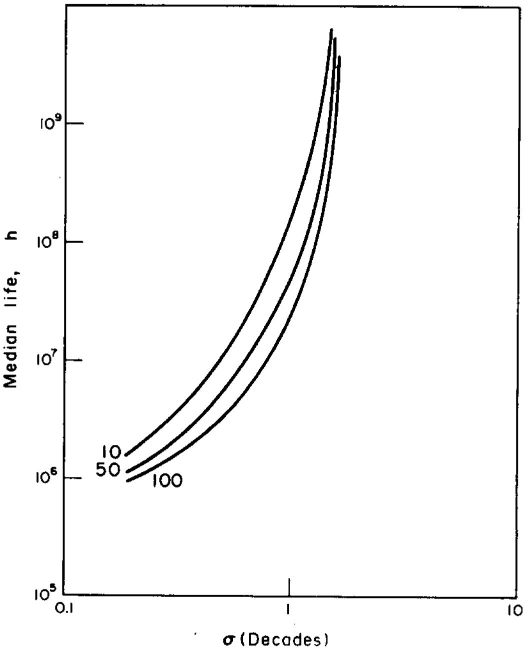

Fig. 7. Minimum median life required, not to exceed 10, 50 or 100 fits (1×10^{-9}/h) due to wear-out during 40 years as a function of dispersion σ in decades.

MEDIAN LIFE REQUIREMENTS

Equipment with a life-expectancy of 40 years has to be built with components with median lives of much more than 40 years. Assuming a maximum failure-rate due to wear out of say 50×10^{-9}/h within 40 years it is simple to specify the minimum median life as a function of σ (See Figure 7). Accelerated tests should then show that the median life of devices at use stress will exceed the limits. This procedure assumes a log-normal distributed life due to wear out which in many cases is a useful approximation, especially for the early part of the wear out distribution.

Purpur plague and corrosion that could be attributed to plastic encapsulated circuits tend to show a dispersion around 0.3. This implies that the median life due to these mechanisms should exceed 2×10^6 h. Other mechanisms that might have dispersions around $\sigma = 1$ should result in median lives exceeding 5×10^7 h. The life of plastic encapsulated circuits is terribly difficult to predict as long as reliable accelerated tests are not available.

CONCLUSIONS

A model for predicting failure-rate as a function of stress and time has been presented. The model can easily fit to existing test data and then be used for predicting purpose at different stresses and elongated times. It is stressed that life tests should be evaluated in order to yield information of median life and lot fraction (%) of weak parts.

All models for predicting failure-rate based upon the assumption of a constant failure-rate, like MIL-HDBK 217 B, are considered to be unrealistic and not consistent with experience from life tests and long time use.

REFERENCES

1. F. H. Reynolds, Thermally accelerated Aging of Semiconductor Components, *Proc. IEEE* 212–222 (Feb. 1974).
2. A. P. Kemény and G. Kalmár, Results of a 160×10^6 device-hour reliability assessment and failure analysis of TTL–SSI. Integrated circuits, Part 1 Test results and electrical failure analysis, *Microelectron. and Reliab.* **14**, 469–498.
3. K. Strandberg, Tillförlitlighetsteknik (Compendium in reliability technique, Telefonaktiebolaget LM Ericsson, in Swedish).