RELIABILITY REPORT

RELIABILITY OF SERIES ULN2000A AND ULN2800A DARLINGTON DRIVERS

This report summarizes accelerated-life tests that have been performed on Series ULN2000/2800A integrated circuits and provides information that can be used to calculate the failure rate at any junction operating temperature.

Product-reliability improvement is a continuous and evolving process. Ongoing life tests, environmental tests, and stress tests are performed to establish failure rates and monitor established process-control procedures. Failures are analyzed to determine design changes or process improvements that can be implemented to improve device reliability.

The reliability of integrated circuits can be measured by qualification tests, burn-in and accelerated-life tests:

1) Qualification testing is performed at an ambient temperature of +125°C, reduced so as to limit junction temperature to +150°C, for 1000 hours with an LTPD = 5 in accordance with MIL-STD-883. This testing is normally conducted in response to a specific customer request or requirement. Qualification testing highlights design problems or gross processing problems, but does not provide sufficient data to generate accurate failure-rate data in a reasonable period of time.

2) Burn-in is intended to remove infant-mortality rejects and is conducted at +150°C for 96 hours or at +125°C for 168 hours. An analysis of test results from the burn-in program found that most failures are due to slight parametric shifts. Catastrophic failures, which would cause user-equipment failure, are typically less than 0.1%.

3) Accelerated-life testing is performed at junction temperatures above +125°C and is used to generate failure-rate data.

ACCELERATED-LIFE TESTS

Accelerated-life tests are performed on integrated circuits at junction temperatures of +150°C or +175°C at the recommended operating voltages. The internal power dissipation on some high-power circuits requires the ambient temperature to be lower than +150°C to keep the junction temperature between +150°C and +175°C.

In these tests, failures are produced so that the statistical life distribution can be established. The distribution cannot be established without failures. High-temperature accelerated-life testing is necessary to accumulate data in reasonable time periods. It has been established that the failure mechanisms at all temperatures in these tests are identical. Temperatures above +175°C are not generally used for the following reasons:

a) Industry-standard molding compounds degrade and release contaminants (halides) at approximately +200°C.

b) Life-test boards constructed with materials capable of withstanding exposure to temperatures greater than +175°C have been deemed to be cost prohibitive.

c) Increases in junction leakage currents may increase the power dissipation and device temperature to an indeterminate level.

Tables Ia and Ib contain data produced by life tests that were conducted at +150°C and +175°C. The data include the number of units in each sample, and the time periods during which failures occurred. The total time-on-test varies, with priority changes influencing allocation of oven and board space, as new products are introduced. The time intervals between test readings were chosen for ease of plotting on log-normal paper.

The acceleration factor calculated using the Arrhenius equation, and a 1 eV activation energy, is approximately 5 x for each 25°C temperature rise in junction temperature and is multiplicative.[1] This allows the data to be compared to qualification life-test data by equating 200 hours at +150°C to 1000 hours at +125°C.

The data at the bottom of Table Ia and Ib were compiled by calculating the probability of success (P_s), the cumulative probability of success, the probability of failure (P_f) and the percentage of failed units in each time period.

CUMULATIVE PERCENT FAILURES

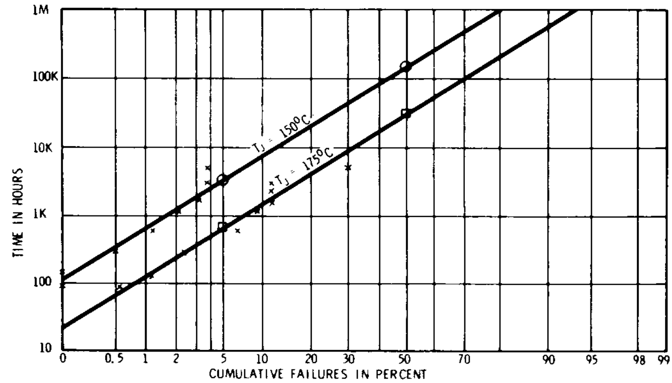

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FIGURE 1

The cumulative percent of failures is plotted on log-normal plotting paper in Figure 1. This paper has a logarithmic time-scale axis and a probability-scale axis. A log-normal distribution plots as a straight line. A line of best fit is drawn through the plotted points and extended to determine the median life-time at the 50% fail-point. The median life at a junction temperature of +150°C is, in this case, 1.6 x 10^5 hours. At +175°C, the median lifetime is 3.0 x 10^4 hours.

The log-normal distribution is commonly used because most semiconductor device data fit such a distribution.[2] When the median life has been found at the elevated temperature, it can be converted to the lower temperature of the actual application. The Arrhenius equation, which relates the reaction rate to temperature, is used to make this conversion.[1]

TABLE Ia
TEST RESULTS at T_J = +150°C

TEST NUMBER	QTY.	90	150	300	600	1200	1800	2400	3000	5000
		HOURS ON TEST / NUMBER OF FAILURES								
1	12	0	0	0	0	2	0	—	—	—
2	22	0	0	0	0	0	0	0	0	—
3	22	0	0	0	0	0	0	0	0	—
4	22	0	0	2	0	0	3	0	0	—
5	22	0	0	0	0	0	0	0	0	—
6	22	0	0	0	0	0	1	0	0	—
7	12	0	0	0	0	0	0	—	—	—
8	12	0	0	0	0	0	0	—	—	—
9	90	0	0	0	2	0	0	—	—	—
10	12	0	0	0	0	0	0	—	—	—
11	12	0	0	0	0	0	0	—	—	—
12	12	0	0	0	0	0	0	0	0	—
13	12	0	0	0	0	0	0	0	0	—
14	35	0	0	0	0	0	0	1	—	—
15	12	0	0	0	1	1	0	0	0	0
16	25	0	0	0	0	0	—	—	—	—
17	25	0	0	0	0	0	—	—	—	—
TOTAL ON TEST		381	381	381	379	376	323	173	138	10
TOTAL FAILURES		0	0	2	3	3	4	1	0	0
TOTAL GOOD		381	381	379	376	373	319	172	138	10
P_S		1.00	1.00	0.995	0.992	0.992	0.988	0.994	1.00	1.00
Cumulative P_S		1.00	1.00	0.995	0.987	0.979	0.967	0.961	0.961	0.961
$P_f = 1 - P_s$		0	0	0.005	0.013	0.021	0.033	0.039	0.039	0.039
Cumulative % Failures		0	0	0.5	1.3	2.1	3.3	3.9	3.9	3.9

The Arrhenius equation is:

$$V_r = V_r^o e^{-\epsilon/kT}$$

where V_r^o = a constant

ϵ = activation energy

k = Boltzmann's constant

T = absolute temperature in degrees Kelvin.

An activation energy of 1.0 electron-volt was established by testing Series ULN2000A, Series UDN5710M, and Series UDN2980A devices at multiple temperatures. Failure analysis of devices rejected during that testing also supports this activation energy, as failures were mainly due to increased leakages, reduced beta, and surface inversion.[3]

The median life-point is drawn on Arrhenius graph paper in Figure 2. The Arrhenius plot gives a graphical solution, rather than a mathematical solution, to the problem of equivalent median lifetime at any junction temperature. A line is drawn through this point (or points when multiple temperatures are used) with a slope of ε = 1.0 eV.

Although not as statistically accurate as the median lifetime, the 5% fail-point can be read from Figure 1 and plotted parallel to the median-life line in Figure 2.

The median life at reduced junction temperatures can now be determined using Figure 2. It must be emphasized that this is junction temperature and *not* ambient temperature. The temperature rise at the junction due to internal power dissipation must be taken into account using the formula:

$$T_J = P_D R_{\theta JA} + T_A \text{ or } T_J = P_D R_{\theta JC} + T_C$$

The median lifetime, or 50% fail-point, as graphically determined in Figure 2, is approximately 100 years at +125°C or 1,000 years at +100°C junction temperature.

The approximate failure rate (FR) may be determined from FR = 1/Median Life, where Median Life is taken from Figure 2 at the

TABLE Ib
TEST RESULTS at T_J = +175°C

TEST		HOURS ON TEST								
		90	150	300	600	1200	1800	2400	3000	5000
NUMBER	QTY.	NUMBER OF FAILURES								
1	25	0	0	0	7	—	—	—	—	—
2	25	0	0	0	0	0	0	0	—	—
3	25	0	0	1	2	1	0	0	—	—
4	24	0	1	0	1	0	0	0	0	—
5	19	0	0	0	0	0	2	—	—	—
6	19	0	0	0	0	0	0	—	—	—
7	12	0	0	2	3	0	—	—	—	—
8	12	0	0	0	0	0	—	—	—	—
9	12	0	0	0	0	0	0	—	—	—
10	18	0	0	0	0	0	—	—	—	—
11	12	0	0	0	0	0	2	0	0	2
12	12	0	0	0	0	0	0	—	—	—
13	12	1	0	0	0	0	0	0	—	—
14	18	0	0	1	2	0	7	—	—	—
15	12	1	0	0	0	0	0	—	—	—
16	12	0	0	0	0	0	—	—	—	—
17	24	0	0	0	0	0	0	—	—	—
18	12	0	1	0	1	0	0	0	0	—
19	24	0	0	0	0	0	—	—	—	—
TOTAL ON TEST		329	327	325	321	287	213	99	42	10
TOTAL FAILURES		2	2	4	16	3	9	0	0	2
TOTAL GOOD		327	325	321	305	284	204	99	42	8
P_S		0.994	0.994	0.988	0.950	0.990	0.958	1.00	1.00	0.800
Cumulative P_S		0.994	0.988	0.976	0.927	0.917	0.879	0.879	0.879	0.703
$P_f = 1 - P_s$		0.006	0.012	0.024	0.073	0.083	0.121	0.121	0.121	0.300
Cumulative % Failures		0.6	1.2	2.4	7.3	8.3	12.1	12.1	12.	30.0

intersection of the junction-temperature line and median-life line. The actual instantaneous failure rate can be calculated using a Goldwaite plot.[4] However, this approximation is very close. At +100°C the failure rate would be:

$$FR = 1/(8.8 \times 10^6 \text{ hours})$$
$$= 0.011\%/1000 \text{ hours} = 110 \text{ FIT}$$

where FIT = failures per 10^9 unit-hours

Other failure-rate values have been calculated and appear in Table II.

CONCLUSION

The relationship between temperature and failure rate is well documented and is an important factor in all designs. Load currents, duty cycle, and ambient temperature must be considered by the design engineer to establish a junction-temperature limit that provides a failure rate within design objectives.

Figure 2 shows that a design with a continuous operating junction temperature of +100°C (internal power dissipation plus external ambient temperature) would reach the 5% failure point in 10 years. Lowering the junction temperature to +70°C increases the time to the 5% failure point to 300 years.

A complete sequence of environmental tests, including temperature cycle, pressure cooker, and biased humidity tests, are continuously monitored to ensure that assembly and package technology remain within established units.

The environmental tests and accelerated-life tests establish a base line for comparisons of new processes and materials.

REFERENCES

1) Manchester, K. E., and Bird, D. W., "Thermal Resistance: A Reliability Consideration," *IEEE Transactions*, Vol. CHMT-3, No. 4, 1980, pp. 580-587.

2) Peck, D. S., and Trapp, O. D., *Accelerated Testing Handbook*, Technology Associates, 1978, pp. 2-1 through 2-6.

3) *ibid.*, p. 6-7.

4) Goldwaite, L. R., "Failure Rate Study for the Log-Normal Lifetime Model," *Proceedings of the 7th Symposium on Reliability and Quality Control*, 1961, pp. 208-213.

MEDIAN LIFE

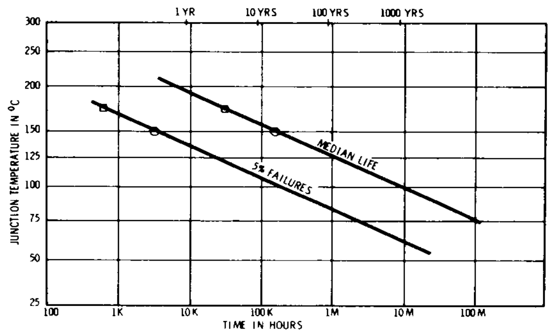

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FIGURE 2

TABLE II
SERIES ULN2000/2800A FAILURE RATE

T_J (°C)	Median Life (h)	Failure Rate (%/1000 h)	Failures In Time (No./10^9unit-hours)
125	1.0×10^6	0.10	1000
100	8.8×10^6	0.011	110
75	1.0×10^8	0.0010	10
50	8.8×10^8	0.00011	1.1