Reliability and MTBF Application Note

Reliability for a GaAs MMIC defined as the probability that it will meet its specifications (with margin) under predefined operating conditions for a known period of time. Reliability is typically expressed in failures in time, or as a FIT rate. A FIT is a failure per billion device hours. Two other commonly used parameters are the mean time between failures (MTBF) and the mean time to failure (MTTF). The cumulative failure increases with time as shown in figure 1. Three distinct areas can be observed. There is the early failure period where most devices with a flaw or defect fail quickly. The mid section where the failure rate is a constant typically defines the useful life a product. The third region shows an increase in failure rate due to wear-out.

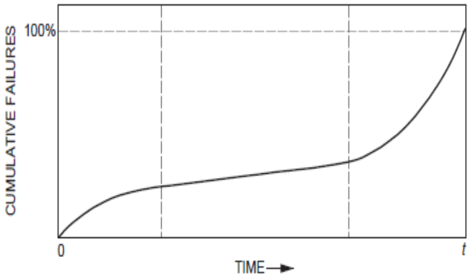

Figure 1. Semiconductor cumulative failure distribution

The reliability failure rate is the slope of the cumulative failure distribution. The general shape of the failure rate of a population over time has been observed to follow a "bathtub" curve (Fig 2), where the failure rate is initially high due to infant mortality, decreases to a low failure rate during the useful life, and, finally, increases again as wear-out sets in. Burn-in is used to remove the devices that make up the early failures before the product is shipped.

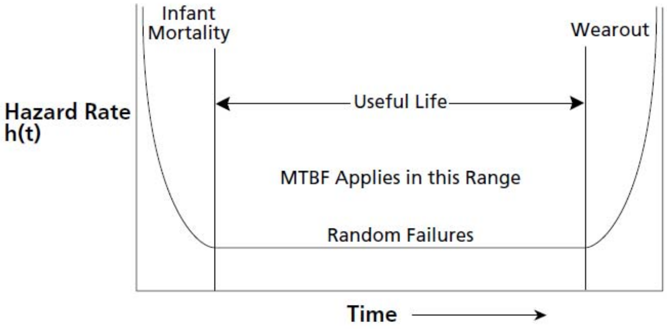

Figure 2. Semiconductor failure rate

There are a large number of physical and process variations and factors that affect reliability and defects are almost always present in some form in the final product. The defects can be fundamental design flaws or physical imperfections that are introduced in the manufacturing process. Some defects are apparent at initial test resulting in immediate device failure, while others only become apparent after the device has been operating for a period of time. Operating conditions are very important and some defects are generated when the device is operated under extreme operating conditions (either DC, RF, or environmental). For this reason, most devices are designed to operate under and within specified operating and environmental conditions. Defects generally result in device performance degradation or failure. Prototype units are put through rigorous reliability tests to uncover weaknesses. Before releasing to production, the reliability of the part is improved as causes for failure mechanisms are determined and eliminated.

A MMIC failure is typically defined as > 10% deviation of a specific parameter (e.g. Gain, Bias Current, Output power, Phase noise) from its original value. Typical factors that influence the failure rate of MMICs are: temperature, power, bias, electrostatic discharge and humidity. Both passive and active components of MMICs must be considered during reliability analysis. However, the dominant failure components is usually due to active devices (e.g. pHEMT, HBT, etc.). Accelerated-life testing is typically used to analyze the reliability of MMICs and to ensure > 10^6 hours of MTBF. The failure rate (f) is defined as the number of units failing per unit of time. In practice, the number of components failing per 10^9 hours is quoted and is known as the FIT. The mean number of failures in a given time is defined by the mean time between failures (MTBF). In the middle section of the bathtub region (Fig. 2), we can assume the failures occur randomly at a constant failure rate, the MTBF is then calculated as

$$MTBF = 1/f$$

The probability of zero failures (P) at time t equals to

$$P = \exp(-t/MTBF)$$

To calculate the failure rates for any given failure mechanism, a relatively large number of samples must subjected to actual use conditions. Since most applications require device lifetimes of > 10^6 hours, accelerated-life tests at higher stress conditions are conducted. In an accelerated test, MMICs are subjected to elevated temperatures to reduce the time to failure thus enabling data to be obtained in a shorter time than would otherwise be required. The Arrhenius equation shows the dependence of a failure rate with temperature:

$$f = A \exp(-E_a/kT)$$

E_a= Activation energy for a given process (eV)
k = Boltzman' s constant, $8.6171\text{x}10^{-5}$ (eV / K)
T= Temperature in Kelvin (273+C)
A= Coefficient

To calculate E_a, failure rates are measured and fitted to the above equation at typically 3 elevated junction temperatures. The median life from each of the 3 tests is fitted with a straight line on an Arrhenius plot. The slope of the line is calculated as the activation energy. Figure 3 shows a typical Arrhenius plot for a power pHEMT.

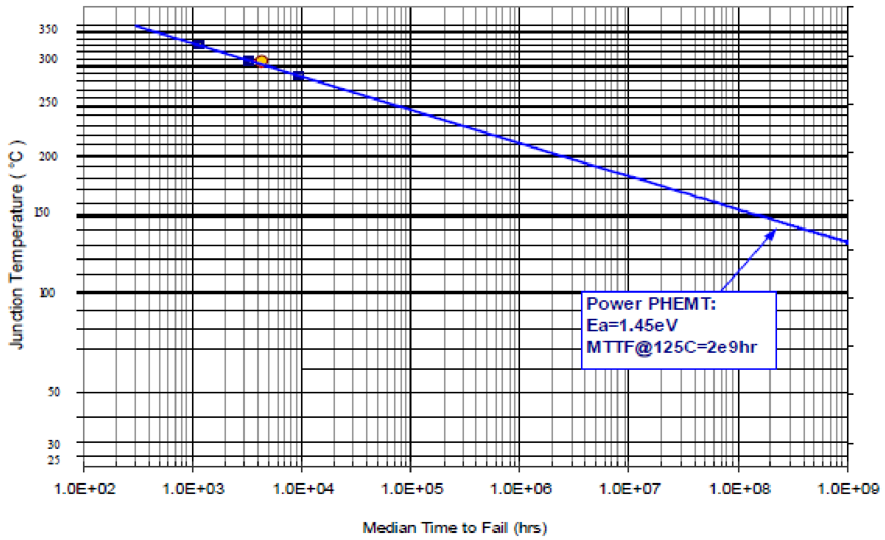

Figure 3. Arrhenius Plot

A primary difficulty in applying thermally accelerated lifetime testing is associating the device degradation that occurs at elevated temperatures with a failure mechanism that is dominant under use conditions. Another step to analyze life-test data is the use of an appropriate mathematical model for the failure distribution. A lognormal distribution is commonly used to fit the measured reliability life test data. The lognormal graph is a plot of normal cumulative percent-failure versus log time. The closer a life-test data fits a straight line on this graph, the better the fit to a lognormal distribution is. Since a limited number of devices are used in the accelerated life test, a confidence limit must be placed on the distributions to indicate the extent to which the data are representative of a batch of components. The sample size determines the confidence in the lifetime predictions. The smaller the sample size, the less confidence we have in the prediction. Confidence limits are defined in terms of percentage. For example, an upper and lower 90% confidence limit would indicate that in repeating the life test 10 times, 9 out of 10 tests would predict a median life between the two limits.

Using accelerated life test, FIT can be calculated as

$FIT=\square^2(\square,\square)*10^9/(2*t*N*AF)$

t= Test time
N=Number of Samples
AF=Acceleration Factor= $\exp(E_a/kT_a- E_a /kT_s)$
$\square^2(\square,\square)$= Chi-Square function
□ = 1-confidence level, e.g. 0.1 for 90% confidence
□ = Degree of Freedom=2*n+2 where n is # of failures

T_a is the operating temperature and T_s is the accelerated test temperature (in Kelvin).

For a constant failure rate, the Chi-Square distribution $\square^2(\square,\square)$ may also be used to calculate confidence intervals around a measured mean time between failures (MTBF) based on MIL-HDBK-781A. If n failures are observed after time t in a time truncated test:

Lower MTBF limit: $2*t/(\square^2(\square/2, 2n+2)$
Upper MTBF limit: $2*t/(\square^2(1-\square/2, 2n)$

In a failure truncated test:

Lower MTBF limit: $2*t/(\square^2(\square/2, 2n)$
Upper MTBF limit: $2*t/(\square^2(1-\square/2, 2n)$

Example:
77 VCO MMICs are stressed at 150°C junction temperature for 2000 hours with 0 failures. The 90% confidence FIT for operating at 80°C is calculated as:

t=2000 hrs
N=77
T_a= 80+273=353
T_s= 150+273=423
□ = 0.1
□ = 2

AF=374
$\square^2(ı,\square)$ = 4.61

FIT=40
MTTF=2.5×10^7 hours

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