**Reliability and Failure Analysis**

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Penerbit Universiti Malaysia Perlis

Kangar • 2021

***FOR UniMAP INTERNAL CIRCULATION ONLY***

*Teaching Module*

*Reliability and Failure Analysis*

Printed in 2021

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*Published by :*

Penerbit UniMAP/UniMAP Press

Universiti Malaysia Perlis

No. 11 dan 13, Jalan Tiga,

Pusat Perniagaan Pengkalan Jaya,

01000 Kangar, Perlis.

Tel: 04-9775159, Faks:04-977 5135

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**PREFACE**

The subject of ‘Reliability and Failure Analysis’ can be considered as a core subject for engineering students, especially for those who specializes in microelectronic engineering. This is as one deals with fabrication of micro/nanoelectronics devices, one must also know the common failures associated with it and how to proceed upon encountering these failures. Thus, this subject mainly focuses on the different approaches and techniques used in conducting analysis on failed semiconductor devices.

It is found that, majority of books and references on this subject-matter that are available in the market are of hundreds of dollars which make it quite unaffordable to students. Thus, this module is initiated as a mean to make up for the lack of affordable textbooks. The contents of this module are compiled from various sources to ensure that it is in-line with the teaching plan and at the same time are relevant to the current developments in the semiconductor industry.

This module is divided into two major parts which are of Reliability and Failure Analysis respectively. However, a major portion of this module focuses on the topic of failure analysis. At the end of each chapter, sample questions are also provided to test the understanding of the students for each topic learnt.

Lastly, it is hoped that this module would be beneficial to the students and serves as an alternative for sources of information in the field of semiconductor failure analysis.

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2021

**CHAPTER 1**

**OVERALL VIEW OF RELIABILITY**

**1. 1 TERMS AND DEFINITIONS IN RELIABILITY**

1. **Reliability** *refers to* the probability that a component or a system will perform a required function for a given period of time when used under stated operating conditions (0-1or 0 to100%)
2. **Failure Rate (FR)** *refers to* the unit of measurement used in the field of reliability engineering. It is expressed as the ratio of the total number of failures to the total operating time.

𝜆=𝐾/𝑇

where:

 *λ* = Failure Rate (FR) e.g failures per hour, per cycle

 K = Number of Failures

 T = Total Operating Time

1. **Mean-Time-Between-Failure (MTBF)** *refers to* the mean (average) time between failures of a system. It is the reciprocal of the failure rate.

$$MTBF= \frac{T}{K}$$

$$MTBF= \frac{1}{λ}$$

1. **Mean-Time-To-Repair (MTTR)***refers to* the average time between failing and being returned to service. Also known as Mean Down Time (MDT). It is being used to calculate system availability and downtime.

 MTTR = Total downtime / No. of failures



where m is total number of units

Ti is the corrective maintenance or repair time needed to repair unit *i* ;

 for *i =1, 2, 3…m*

 λi is the constant failure rate of unit *i ; for i =1, 2, 3, ….m*

1. **Availability** of a module*refers to*the percentage of time when system is operational.

$$Availability= \frac{Uptime}{Uptime+Downtime}$$

$$Availability= \frac{MTBF}{MTBF+MTTR}$$

**1.2 RELIABILITY DISTRIBUTIONS**

The reliability performance of components can often be described by mathematical expressions. These reliability distributions are derived from the same frequency distributions that are used in the area of probability where they provide an analytical representation of all possible outcomes.

## **1.2.1 Exponential Reliability Distribution**

When a device is subject only to failures that occur at random intervals, and that expected number of failures is the same for equally long operating periods (the failure rate, λ is constant), its reliability function, R(t) is exponentially based and is expressed as:

𝑅(𝑡)=𝑒−𝜆𝑡

*R* = Reliability

*e* = base of the natural logarithm

*λ* = chance of failure (constant)

*t*  = operating time for which we are measuring the reliability or *R* of the device that is known as the exponential case of chance failure.

The unreliability of the system, Q(t) is expressed as:

𝑸(𝒕)= 𝟏 −𝑹(𝒕)=𝟏 − 𝒆−𝝀𝒕

## **1.2.2 Poisson Reliability Distribution**

If a component having a constant failure rate, *λ* is immediately repaired or replaced upon failing, the number of failures observed over a time period, *t* has a Poisson distribution. Unlike the failure distribution that is continuous over time, the Poisson distribution is discrete. The probability of observing *n* failure in time *t* is given by:

$$p\_{n}(t)=\frac{e^{-λt}(λt)^{n}}{n!}$$

If *S* spare components are available to support continuous operation over a time period *t*, then



is the cumulative probability of *S* or fewer failures occurring during time *t*. Therefore, *Rs(t)* is the component reliability if there are *S* spares available for immediate replacement when a failure occurs.

## **1.2.3 Binomial Reliability Distribution**

The Binomial Reliability Distribution is a discrete distribution. Let *x* be the discrete random variable representing the number of successes in *n* independent trials where the probability of success on each trial is a constant *p*. The probability function can then be represented by:



where x = 0,1,…..n and



## **Weibull Reliability Distribution**

The Weibull Reliability Distribution is a complex continuous reliability distributions where failure rates are not CONSTANT all the time. Weibull reliability distribution is similar to exponential reliability function with additional shaping parameter.

𝑹𝒕= 𝒆−(𝜶𝒕)𝜷

where as α : failure rate

 β:shape parameter (it indicates whether the FR decrease/increase)

If β < 1.0 , failure rate is decreasing

 β = 1.0 , failure rate is constant

 β > 1.0 , failure rate is increasing

* 1. **SYSTEM RELIABILITY MODELS**

How the components are connected to each other determines what type of system reliability model is used and, ultimately, the reliability value for the system.

Types of System Reliability Model:

1. **Series Configuration**
* The simplest reliability model.
* Each component of the system needs to be working for overall system success.

 

Reliability, Rs , for N component in this system



If each component has a constant failure rate (CFR) of λi, the system reliability is given by:



1. **Parallel Configuration**

By adding a factor of redundancy to the model, the system reliability can be improved. Many types of parallel configuration can be used:

* **Active Parallel Configuration (Redundancy)**

In this case, only one of the redundant components must be working to maintain the system’s levels of service. The system will only fail if all the components fail.



* **Standby Parallel Configuration (Redundancy)**

In the standby reliability model, only one component is activated at a time and if this component should fail, switching goes to the next component that is hooked up in parallel with the first component.

The overall reliability is calculated as a two-part configuration:

(1) the reliability of the first component and

(2) the reliability of the second part after the first part fails.



$$R\_{s}(t)=e^{-λt}\sum\_{i=0}^{n-1}\frac{\left(λt\right)^{i}}{i!} $$

* ***k*-out-of *n* Parallel Configuration (Redundancy**)

The *k*-out-of-*n* configuration is a special case of parallel redundancy. This type of configuration requires that at least *k* failure modes do not happen out of the total *n* parallel failure modes for the product to succeed. The simplest *k*-out-of-*n* configuration is when the failure modes are independent and identical and have the same failure distribution and uncertainties (in other words, they are from the same test data). The reliability of the product with such configuration can be evaluated using the binomial distribution, or:

The probability of *k* or more successes from among the *n* components is given by:



where x are the successes (non-failures) that can be obtained from n components and

 

If *k*=1, complete redundancy occurs, and if *k*=*n*, the *n* components are, in effect, in series

1. **Combined Configuration**

It represents by a combination-style reliability model that consists of a number of simpler reliability models that were described in the previous sections. The overall reliability can be determined by first calculating the reliability of the smaller or simple individual portions first and then combining each of these portions to determine the overall reliability.



**1.4 TEST YOUR UNDERSTANDING:**

1. Calculate the Failure Rate for a washing machine that has accumulated 5 failures that resulted in 5 service calls during 1,200 hours of operation.

2. Calculate the MTBF for a washing machine that has accumulated 5 failures that resulted in 5 service calls during 1,200 hours of operation.

3. What is the reliability of an electrical device that has an exponential reliability

 distribution with a failure rate, λ of 9 X 10-6 over time t = 1000 hours?

4. What is the probability of

1. one failure ; or
2. two failures

 occurring during a time period of 1,000 hours for an electronic device with a failure rate

 of 100 X 10-6?

5. Banks have card readers on the outside doors to individual branches for access to the

 ATM lobby for off-banking hours. In this example, a bank has decided to use two card

 readers hooked up in parallel redundancy where the customer can use either card

 reader to gain entry to the lobby. Assume that the percentage of failure for the card

 reader is 5%, find the overall system reliability, *Rs*

6. A space vehicle requires three out of its four main engines to operate in order to achieve orbit. If each engine has a reliability of 0.97, determine the reliability of achieving orbit.

7. Formulate the overall reliability of LCD display unit that consist of a display, backlighting panel and a number of circuit board with the following setup. Please include the model diagram in your answer.

* An LCD panel with hardware failure rate, λ1
* A backlighting board with 10 bulbs with individual bulb failure rate of λ2 but still considered good with 2 bulbs failures
* 2 microprocessor boards A and B hooked up in parallel, each with total circuit board failure rate of λ3
* Dual power supplies, C and D in a standby redundancy, with a failure rate of λ4 for each power supply
* EMI board with failure rate λ5 if hooked up in series with the common input of the power supply C and D.

8. Consider a four-component system of which the components are independent and identically distributed with Constant Failure Rate (CFR). If Rs(100) = 0.95 is the specified reliability, find the individual component MTTF.

**1.5 REFERENCES**

Charles E. Ebeling,*“An Introduction to Reliability and Maintainability Engineering”*, McGraw Hill International Edition, 1997