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TECHNICAL REPORT

Reliability of devices used in fibre optic systems – General and guidance

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CONTENTS

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RELIABILITY OF DEVICES USED IN FIBRE OPTIC SYSTEMS – GENERAL AND GUIDANCE

FOREWORD

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IEC 62721, which is a technical report, has been prepared by IEC technical committee 86: Fibre optics.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86/406/DTR	86/412/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

TC86 (Fibre optics) is a group that reviews and implements the standardization of optical fibres and optical cables, optical interconnecting devices, passive and active optical components and modules, and optical sub-systems. As these optical components and modules are used for telecommunications as well as data communications systems, the reliability required for these are extremely high. Since the 1980s, when fibre optic communication systems were first deployed for commercial use, the reliability of optical fibres, optical components and modules has been examined and checked. As a result, reliability theories are nearly completely established for optical fibre, optical connectors, optical passive components and optical active components.

How to check reliability differs depending on the type of optical device. For example, for optical fibres, it is measured by the probability of fibre breaks under the condition of constant stress. Optical passive components are generally tested using accelerated deterioration tests under high temperature and high humidity conditions. For the reliability of laser diodes (LD) (a typical optical active device), the primary failure mode is a decrease of optical output power and an increase of threshold electric current caused by the increase of the leakage of electrical current in the active layers of the LD chip. The lifetime has an inverse correlation with the drive current.

In addition, the industry has established and uses standard reliability evaluation tests developed for the purpose of commercialisation in addition to the approach of estimating the lifetime by failure mode analysis mentioned above.

Information on failure mode and lifetime estimates are discussed and summarised in many documents prepared by the Subcommittees (SC) and Working Groups (WG) of TC86. Test items and conditions for reliability qualification tests are described in documents prepared and set forth by each SC.

RELIABILITY OF DEVICES USED IN FIBRE OPTIC SYSTEMS – GENERAL AND GUIDANCE

1 Scope and objective

This technical report provides information on the IEC documents concerning reliability for optical fibres, optical connectors, optical passive components, optical active components, optical amplifiers, and optical dynamic modules used for optical fibre communications.

Documents on reliability include summaries of reliability theory and quality management methods, technical information on failure mode analysis and failure mechanisms, lifetime and fit-rate estimates using acceleration tests, test items, conditions, and pass/fail criteria in reliability qualification tests, and tests and measurement methods for optical fibres, optical components, and optical modules.

Each SC in TC86 has already created documents on reliability. This technical report provides this information in a user-friendly manner.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068 (all parts), *Environmental testing*

IEC 60749 (all parts), *Semiconductor devices – Mechanical and climatic test methods*

IEC 60793-1 (all parts), *Optical fibres – Part 1: Measurement methods and test procedures*

IEC 60793-1-30, *Optical fibres – Part 1-30: Measurement methods and test procedures – Fibre proof test*

IEC 60794-1-2, *Optical fibre cables – Part 1-2: Generic specification – Basic optical cable test procedures*

IEC 61290 (all parts), *Optical amplifiers – Test methods*

IEC 61291-5-2, *Optical amplifiers – Part 5-2: Qualification specifications – Reliability qualification for optical fibre amplifiers*

IEC 61300 (all parts), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures*

IEC 62005 (all parts), *Reliability of fibre optic interconnecting devices and passive components*

IEC 62007-2, *Semiconductor optoelectronic devices for fibre optic system applications – Part 2: Measuring methods*

IEC 62150 (all parts), *Fibre optic active components and devices – Test and measurement procedures*

IEC 62343-2, *Dynamic modules – Part 2: Reliability qualification*

IEC 62343-5-1, *Dynamic modules – Test methods – Part 5-1: Dynamic gain tilt equalizer – Response time measurement*

IEC 62572-3, *Fibre optic active components and devices – Reliability standards – Part 3: Laser modules used for telecommunication*

IEC/TR 62048, *Optical fibres – Reliability – Power law theory*

IEC/TR 62343-6-6, *Dynamic modules – Part 6-6: Failure mode effect analysis for optical units of dynamic modules*

IEC/TR 62572-2, *Fibre optic active components and devices – Reliability standards – Part 2: Laser module degradation*

IEC/TR 62627-03-01, *Fibre optic interconnecting devices and passive components – Part 03-01: Reliability – Design of an acceptance test for fibre pistoning failure of connectors during temperature and humidity cycling: demarcation analysis*

3 Generic information on reliability

Reliability generally means the characteristics of keeping the required performance over a long period of time and/or on repeated operation (driving). Components and modules degrade and finally fail after long term operation. Reliability is usually expressed in this case as failure rate per unit time (e.g. hours) or a time. The curve of the failure rate is called a bathtub curve, and is generally divided into three regions: initial failure region, random failure region, and wear-out failure region. Screening tests are sometimes applied to reduce the initial failure rate. In the random failure region, the failure rate is independent of the operating time. In the wear-out failure region, the failure rate increases as operating time extends. Generally, reliability is expressed by the failure-in-test (fit) rate in the random failure region, and in the wear-out failure region by the accumulated failure rate depending on the operating time of the product.

There are two types of reliability: design reliability and field reliability. Design reliability is generally estimated by accelerated test results and/or calculated by a cumulative total of fit rates of the parts and materials. Field reliability is generally calculated by the total failures and the total operating hour volume in the field.

The following shows the standard approach to design reliability:

– Conducting a failure mode analysis and analysing the performance of the parts which degrade and the factors that accelerate degradation;
– Determining the acceleration test conditions and the pass/fail criteria based on the results of failure analysis;
– Carrying out acceleration tests under different conditions and obtaining the appropriate functions to indicate the lifetime (i.e. the failure function (Weibull distribution, lognormal distribution)) and the acceleration factor;
– Carrying out lifetime tests under suitable conditions of the accelerated tests to obtain more accurate parameters for the lifetime distribution function and calculating the failure rate and the accumulated failure rate.

Besides the reliability estimate obtained in the procedures based on the failure mode analysis described above, conventional reliability qualification tests have been used for many types of optical components and modules that consider the component environment. In particular, merchantability is often determined by the result of reliability qualification tests for modules that are composed of several components and other functional components for which the failure mode is difficult to identify.

4 IEC documents on reliability in TC86

4.1 General

TC86 (Fibre optics) consists of three Subcommittees: SC86A (Fibres and cables), SC86B (Fibre optic interconnecting devices and passive optical components) and SC86C (Fibre optic systems and active devices).

There are different approaches to failure mode and reliability depending on the products handled by each Subcommittee.

It is generally known that a failure mode for silica-based optical fibres is where a small crack on the surface and/or inside the fibre grows by constant stress and leads to fibre breaks.

The degradation mode and degradation accelerating factors for optical connectors and optical passive components are very complex, as these optical components are fabricated by several types of parts made from different materials. Reliability is determined by failure mode analysis and based on the acceleration rate and reliability estimate result obtained by such analysis. Another approach to ensure reliability is to conduct a reliability qualification test in the user environment.

For a laser diode it is known that optical output power is decreased by the increase of electrical current leakage in the active layers in the LD chip. It is caused by dislocation growth and formation of dark spots and dark lines in the active area of the laser diode. This degradation mode is one of the typical wear-out failures and information on this failure has been sufficiently collected. In order to evaluate the reliability of the LD module, not the LD chip itself, the test methods for passive optical components are generally applied.

Optical fibre amplifiers and dynamic modules are typically modules or sub-systems composed of optical passive and active components. Reliability of these modules or sub-systems is reliant on the reliability of the parts of the modules or sub-systems. Reliability (fit rates) of modules is generally calculated by the cumulative sum of the fit rates of individual optical component parts. Besides the estimation of the failure fit rate, some types of aging (long-term operation) tests and mechanical tests are required to check the effect after mounting the component parts.

Information on reliability includes failure mode analysis, lifetime estimate by acceleration tests, and reliability qualification tests in addition to the general items on quality and reliability. TC86 SCs and WGs have developed and published various documents relating to quality and reliability in each product group.

Table 1 shows the TC86 classification mentioned above. Measuring methods are described in the table, as the application of these in each test is important to confirm the reliability and performance.

Failure and degradation relating to higher power is also of interest although different from the issue of long-term reliability. Annex A gives a list of documents relating to higher power that are published or in process within TC 86.

Table 1 – IEC documents on reliability of fibre optic devices

Types of contents	Optical fibre and cable	Optical passive components	Optical amplifiers	Optical active devices	Dynamic modules
Generic of reliability and quality	None	IEC 62005-1 IEC 62005-4 IEC 62005-5[a] IEC 62005-7	IEC 61291-5-2	IEC 62572-3	IEC 62343-2
Failure mode and/or degradation analysis	TR 62048	IEC 62005-3	None	IEC/TR 62572-2	IEC/TR 62343-6-6
Lifetime estimation and/or fit rate calculation	TR 62048	IEC 62005-2 IEC/TR 62627-03-01	IEC 61291-5-2	IEC/TR 62572-2	IEC 62343-2
Reliability qualification test	60793-1-30	IEC 62005-9-1[a] IEC 62005-9-2 IEC 62005-9-4[a]	IEC 61291-5-2	IEC 62572-3	IEC 62343-2
Test and measurement	60793-1 series 60794-1-2	IEC 61300 series	IEC 61290 series	IEC 60068 series IEC 60749 series IEC 62007-2 IEC series	IEC 62343-5 series

[a] To be published.

Details of reliability documents for each optical device are given in 4.2 to 4.6.

4.2 Reliability documents for optical fibres and cables

4.2.1 General

The reliability for silica optical fibre is described in IEC/TR 62048, which indicates how to estimate and calculate the reliability of optical fibre under constant stress.

Break modes are roughly classified into dynamic fatigue and static fatigue. Test methods of dynamic fatigue and static fatigue are defined by IEC 60793-1-33. The characteristics of dynamic fatigue can be obtained by measuring the stress rate dependency of the break stress. The characteristics of static fatigue are obtained by measuring the static stress dependency found during the time to break.

Lifetime is estimated from the static fatigue measurement. A Weibull distribution is generally applied to the lifetime distribution, and the failure rate and the estimated lifetime are expressed as the time to break per fibre length. Parameters are derived by plotting the accumulated failure rate for the break strength or the time to break on an approximate Weibull distribution chart to obtain the failure rate and the lifetime.

To ensure fibre strength, proof screening is commonly adopted. The detail of the proof screening method is defined in IEC 60793-1-30.

The documents noted above are reliability documents for silica fibres. The reliability of plastic optical fibre (POF) is for further study.

Various environmental tests for optical fibres and cables are defined in the IEC 60793-1 series and IEC 60794-1-2. These environmental tests are established for known environments during transportation, installation and on-site operation.

4.2.2 IEC 60793-1-30, *Optical fibres – Measurement methods and test procedures – Fibre proof test*

This international standard defines details of the screening test method. The proof screening method for optical fibres puts a tensile force on the whole length of fibre, so that the part of fibre which is under a certain level of strength breaks during the test. This ensures a minimum strength within the length of the fibre.

4.2.3 IEC/TR 62048, *Optical fibres – Reliability – Power law theory*

This technical report describes detailed procedures of how to calculate the relationship between the elapsed time and the probability of a fibre break under the condition where constant stress is applied to silica optical fibres. A major reason for the fracturing of silica optical fibres is a growing crack on the surface of the optical fibre due to stress. Generally, the calculation is according to the power law theory using empirical parameters.

The formulae utilize parameters obtained from fatigue testing-to-failure under certain service conditions, and from proof testing with potential random failures. The typical service conditions of interest to consider are long lengths in tension, short lengths in uniform bending, and short lengths with uniform bending and tension.

NOTE Optical cables are traditionally designed to separate bending forces from axial tensions. This assumption is not valid for some cables used in building applications. These cables may be subject to bends and tension simultaneously. Under these conditions, the strain from all sources should be taken into account to accurately predict mechanical lifetime at the bend. The resulting failure probability when bends and tension are present can be calculated using the strip calculation found in IEC/TR 62048.

4.3 Reliability documents on optical interconnecting devices and passive optical components

4.3.1 General

Optical interconnecting devices include optical connectors, fibre management systems, splices, and closures.

Reliability of optical interconnecting devices and passive optical components is defined in the IEC 62005 series. The series was prepared by SC 86B/WG5 which was disbanded in 2007. No working draft was prepared for IEC 62005-8, the title of which was *Prior reliability*. It has been decided that all the documents in IEC 62005 series are to be technical reports except the IEC 62005-9 series. The IEC 62005-9 series of documents describes reliability qualification testing. While there are some documents on optical passive components and optical interconnecting devices, no reliability qualification test documents are available on splices and closures. The IEC/TR 62627-03 series consists of technical reports on reliability. IEC/TR 62627-03-02 is not a document for long-term reliability but a report on the test results of high power incidence.

The IEC 61300 series defines tests and measurement methods of fibre optic interconnecting devices and passive components. The IEC 61300-2 series is for test methods, and IEC 61300-3 series is for performance measurement methods. Some of the test methods included in IEC 61300-2 refer to the IEC 60068 series, which is for electric and electronic devices, and includes some notices and explanations for testing passive optical components.

4.3.2 IEC 62005-1, *Reliability of fibre optic interconnecting devices and passive components – Part 1: Introductory guide and definitions*

This international standard gives an outline and guidance on how to use the IEC 62005 series. It describes

- failure mode analysis
- acceleration tests for lifetime estimate
- determination of screening conditions during the process from designing to design verification
- use of field data after the release of the product
- guidelines for using individual documents

- definitions of terms, symbols and abbreviations for reliability
- precautions for the approach to check the reliability of newly developed optical components

4.3.3 IEC 62005-2, *Reliability of fibre optic interconnecting devices and passive components – Part 2: Quantitative assessment of reliability based on accelerated ageing test – Temperature and humidity; steady state*

This international standard contains the guidelines for an accelerated test, and examples of an accelerated test of temperature and humidity for a passive optical component to estimate the lifetime. It refers to the lognormal and Weibull distributions as a typical failure distribution.

It gives an example where temperature acceleration complies with the Arrhenius law and the humidity is proportional to the square of the relative humidity acceleration. It is suggested that 0,4 to 1,2 eV is the typical value of activation energy in the Arrhenius law for the temperature acceleration factor, and that ΔIL=1 dB is a typical standard for judging a failure. A matrix table is also included which indicates the temperature and humidity for acceleration tests. For samples that do not fail during the test period, the estimate is made by extrapolating IL. While performance should be monitored during the test, at least six or more measurements are required in the case where it cannot be monitored.

It shows the procedure to prepare a lifetime distribution based on the test results and to calculate the fit-rate.

In the case of random failures, calculation should be conducted using the field fit rate and/or using the data of long-term reliability testing for one year or longer. In this case, a one-sided upper confidence interval should be used in Poisson approximations, and the Kai squared distribution is used for statistical analysis. In the case of random failure, mishandling by users should be considered.

4.3.4 IEC 62005-3, *Reliability of fibre optic interconnecting devices and passive components – Part 3: Relevant tests for evaluating failure modes and failure mechanisms for passive components*

This international standard explains the method of failure mode effect analysis (FMEA). FMEA tables for passive optical components, optical connectors, and splice are included. FMEA tables are used to summarise the functions, failure modes, and the degradation acceleration factors by each factor for optical passive components that are composed of different parts and materials, and indicates test methods corresponding to each factor. Test items and these conditions for reliability may be analysed using FMEA.

4.3.5 IEC 62005-4, *Reliability of fibre optic interconnecting devices and passive optical components – Part 4: Product screening*

This international standard contains information on screening. It describes the purpose of screening, namely reducing the initial failure and lowering the bathtub curve. Furthermore, it indicates the guidelines to select screening items and conditions (i.e. identifying a failure mode, it is prohibited to shorten the life-time, it should be easy, etc.) and explains the necessity of feedback of field data. Typical screening conditions are also listed. The contents are general and may apply not only to interconnecting devices and passive optical components but also other devices and components.

4.3.6 IEC 62005-5, *Reliability of fibre optic interconnecting devices and passive optical components – Part 5: Relating accelerated tests to standardized service environments*

This proposed new work item describes the accelerated tests corresponding to the standardised service environments and emphasises that the accelerated test should be conducted in each environment category. Typically, an accelerated test is conducted under steady temperature and/or humidity conditions, or under cyclical test conditions. The steady state test accelerates the chemical change, diffusion, corrosion, and water permeation, while the test under cyclical test conditions may also cause a mechanical change by relative expansion and contraction. When selecting the test conditions, it is necessary to consider the failure modes. The document indicates the temperature range in the accelerated test conditions by each environmental category. Furthermore, tables show typical temperature and activation energies in different regions; tropical, moderate and sub-arctic. The information contained there is useful not only for interconnecting devices and passive optical components but also for other devices.

4.3.7 IEC 62005-7, *Reliability of fibre optic interconnecting devices and passive optical components – Part 7: Life stress modelling*

This international standard provides details that should be considered when deciding on the minimum acceleration tests as a life stress model as well as precautions when conducting acceleration tests. The contents of the document are more general than those in IEC 62005-2 and proposed IEC 62005-5 and can be applied not only to interconnecting devices and passive optical components but also to other devices.

4.3.8 IEC 62005-9-1*, Fibre optic interconnecting devices and passive optical components – Reliability – Part 9-1: Qualification of passive optical components*

This draft international standard defines test items and conditions of reliability qualification test for passive optical components in each environmental category, but has no information on pass/fail criteria. It indicates the test items and the conditions for service environmental categories C, U and O. For category O, all the samples are included in one group and should be carried out sequentially. For categories C and U, it is not required to conduct each test sequentially. FMEA (failure mode effect analysis) for passive optical components prepared in IEC 62005-3 is attached in the annex.

4.3.9 IEC 62005-9-2, *Reliability of fibre optic interconnecting devices and passive optical components – Part 9-2: Reliability qualification for single fibre optic connector sets – Single mode*

This international standard defines the reliability qualification test items and the conditions for single fibre, cylindrical ferrule PC (physical contact) optical connectors, and indicates the test items and conditions for service environmental categories C and U. All the tests included in one group should be carried out sequentially.

4.3.10 IEC 62005-9-4, *Fibre optic interconnecting devices and passive components – Part 9-4: High power qualification of passive optical components for environmental category C*

This draft international standard presents the reliability qualification of passive components with respect to use of high power applications for environmental category C. A partial list of such components includes isolators, wavelength division multiplexers, variable optical attenuators and splitters.

4.3.11 IEC/TR 62627-03-01, *Fibre optic interconnecting devices and passive components – Part 03-01: Reliability – Design of an acceptance test for fibre pistoning failure of connectors during temperature and humidity cycling: demarcation analysis*

This technical report describes the analysis result of fibre withdrawal of optical fibre from a ferrule for a cylindrical ferrule optical connector under high humidity conditions. It contains a limitation map of activation energy. It explains the lifetime estimate for two models in temperature and humidity accelerated tests.

4.4 Reliability documents on optical amplifiers

4.4.1 General

Optical amplifiers include optical fibre amplifiers, optical semiconductor amplifiers, and optical waveguide amplifiers. Currently, among the reliability documents for optical amplifiers, only those for optical fibre amplifiers have been issued, and there is no document on reliability for other types of optical amplifiers.

Measurement test methods for each characteristic parameter of optical amplifiers are defined in the IEC 61290 series. In the documentation system of IEC 61290-x-y, "x" indicates the performance parameters to be measured, and "y" indicates the individual measurement method.

Optical amplifiers specifications are defined in the IEC 61291 series. This series covers generic specifications, performance specification templates, qualification specifications and interfaces. There is no document that defines reliability for the control system of optical amplifiers. IEC 61291-6-1 describes the control interface of optical amplifiers.

Optical amplifier technical reports are in the IEC 61292 series. IEC 61292-4 covers the maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers

4.4.2 IEC 61291-5-2, *Optical amplifiers – Part 5-2: Qualification specifications – Reliability qualification for optical fibre amplifiers*

This international standard describes the reliability of optical fibre amplifiers. This document includes precautions for quality assurance between a maker and a user as a general requirement for quality. No information is included on the relation between the failure mode of optical components that constitute a fibre amplifier and that of fibre amplifiers. The annex of this document describes the guidelines for reliability for optical components that constitute an optical fibre amplifier. The reliability of each optical component should be qualified. The reliability of optical fibre amplifiers is calculated by summing the fit rates of individual optical components. Additionally, this document defines the minimum requirement for the reliability qualification test items and conditions for optical fibre amplifiers. The test items include a high temperature aging test and mechanical tests such as mechanical shock.

4.5 Reliability documents on optical active devices

4.5.1 General

Optical active devices include LD (laser diode) modules, PD (photo detector) modules, optical transceivers, optical modulators, and other LD modules that have a function of optical modulation. Although IEC 61751 was published as a document on the reliability of the LD module, it was separated into two documents; IEC/TR 62572-2 and IEC 62572-3. There is no document on reliability for optical receiver modules such as PD modules or for the control systems of optical transceivers.

Performance measurement methods of optical active components are defined in the IEC 62150 series. Measurement methods for LD module for telecommunication purposes are defined in IEC 62007-2. The IEC 60068 series gives the environmental tests for electric and electronic components, and the IEC 60749 series gives the environmental tests for optical active components.

4.5.2 IEC/TR 62572-2, *Fibre optic active components and devices – Reliability standards – Part 2: Laser module degradation*

This technical report explains the internal structure of LD modules and gives the growing dark line in an active layer as a typical failure mode for LD, increase of leak current, and break in the facet. It also covers a typical failure mode for other than an LD chip such as monitor PD and thermo-electric cooler (TEC). The service life test using the Arrhenius formula is described as an accelerated test for the reliability of LD modules. Examples of screening conditions for LD and PD chips are suggested. It also shows typical examples of pass/fail criteria in reliability tests and typical acceleration modules, and explains the failure rate estimate using lognormal distribution.

4.5.3 IEC 62572-3, *Fibre optic active components and devices – Reliability standards – Part 3: Laser modules used for telecommunication*

This international standard describes the requirements for quality assurance, including special precautions for users of LD modules. It defines the reliability qualification test items and conditions, not only for initial qualification tests, but also for periodical reliability assurance tests. The annex describes special precautions for reliability tests of various types of products such as products with or without TEC, LD chip, and PD chip as reference information.

4.6 Reliability documents on optical dynamic modules

4.6.1 General

A dynamic module is an optical module commercialised after 2000. Dynamic modules have various functions, and thus, various internal structures and driving mechanisms. There are two documents on reliability of dynamic modules: IEC 62343-2 and IEC/TR 62343-6-6.

The IEC 62343-4 series, as yet untitled, will define the control interface of dynamic modules.

The IEC 62343-5 series defines tests and characteristic measurement methods of dynamic modules. Regarding the characteristics measurement methods and test methods, documents in this series often refer to the IEC 61300 series that describe test and measurement methods for passive optical components.

IEC/TR 62343-6-2 describes the examination result of hardware and software interfaces of dynamic modules.

4.6.2 IEC 62343-2, *Dynamic modules – Part 2: Reliability qualification*

This international standard divides dynamic modules into two types: products for which reliability can or cannot be analysed by checking the reliability of each component such as optical components, and control components. In the latter case, reliability of individual components should be separately qualified. This document does not include the failure mode analysis of dynamic modules. Failure fit rates of dynamic modules are generally calculated by summing the fit rate of components. The document indicates the minimum requirements of reliability qualification test items and test conditions for two types of dynamic modules. The minimum requirement test items include shock and vibration tests under the operating conditions.

4.6.3 IEC/TR 62343-6-6, *Dynamic modules – Part 6-6: Failure mode effect analysis for optical units of dynamic modules*

This technical report indicates the optical failure mode analysis for various dynamic modules and summarises the functions, degradation modes, acceleration factors, failure mode, and recommended reliability conditions for various components.