Quality Information

Corporate Quality Policy

Our goal is to exceed the quality expectations of our customers. This commitment starts with top management and extends through the entire organization. It is achieved through innovation, technical excellence, and continuous improvement.

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Fig. 1 - Vishay Quality Policy

VISHAY INTERTECHNOLOGY, INC.

ENVIRONMENTAL, HEALTH, AND SAFETY POLICY

Vishay Intertechnology, Inc. is committed to conducting its worldwide operations in a socially responsible and ethical manner to protect the environment, and ensure the safety and health of our employees to conduct their daily activities in an environmentally responsible manner

Protection of the Environment: conduct our business operation in a manner that protects the environmental quality of the communities in which our facilities are located. Reduce risks involved with storage and use of hazardous materials. The company is also committed to continual improvement of its environmental performance

Compliance With Environmental, Health and Safety Laws, and Regulations: comply with all relevant environmental, health and safety laws, and regulations in every location. Maintain a system that provides timely updates of regulatory change. Cooperate fully with governmental agencies in meeting applicable requirements

Energy, Resource Conservation, and Pollution Control: strive to minimize energy and material consumption in the design of products and processes, and in the operation of our facilities. Promote the recycling of materials, including hazardous wastes, whenever possible. Minimize the generation of hazardous and non-hazardous wastes at our facilities to prevent or eliminate pollution. Manage and dispose of wastes safely and responsibly

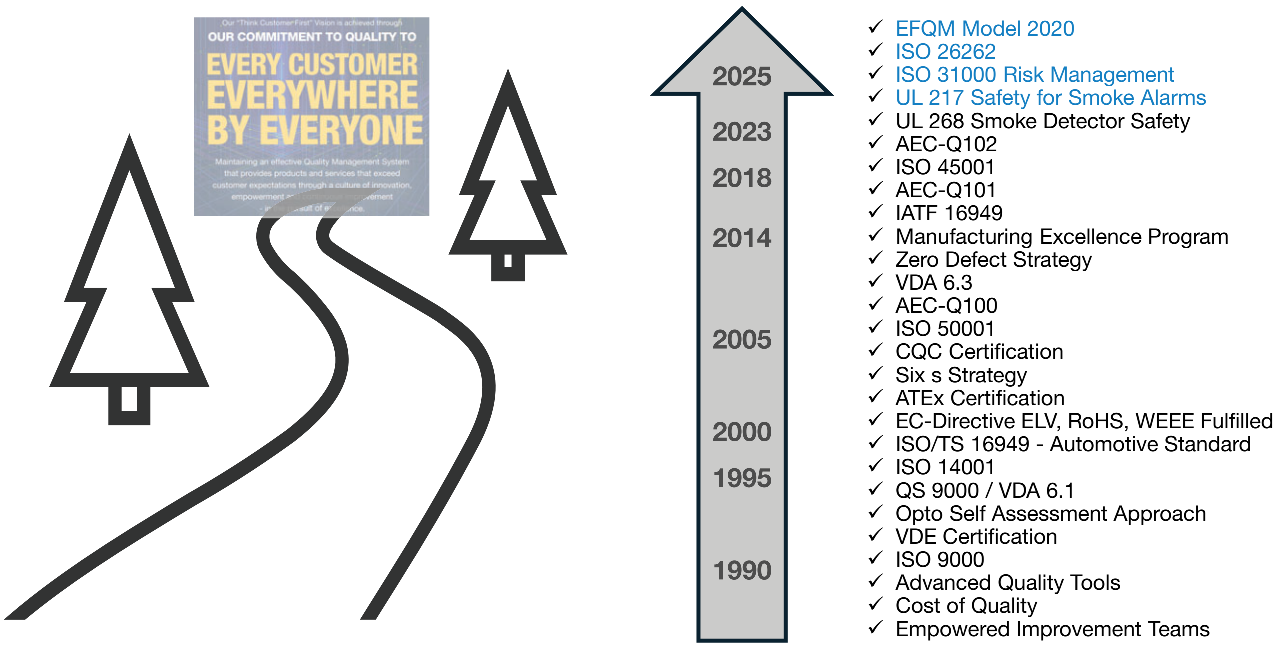


Fig. 2 - Vishay Quality Road Map

QUALITY SYSTEM

QUALITY PROGRAM

At the heart of the quality process is the Vishay worldwide quality program. This program, which has been in place since the early 90's, is specifically designed to meet rapidly increasing customer quality demands now and in the future.

Vishay Corporate Quality implements the Quality Policy and translates its requirements for use throughout the worldwide organization.

Vishay quality has defined a roadmap with specific targets along the way. The major target is to achieve world-class excellence throughout Vishay worldwide.

VISHAY CORPORATE QUALITY

The Vishay corporate quality defines and implements the Vishay quality policy at a corporate level. It acts to harmonize the quality systems of the constituent division and to implement total quality management throughout the company worldwide.

Vishay Zero Defect Program

- Exceeding quality expectations of our customers
- Commitment from top management through entire organization
- Newest and most effective procedures and tools
  - Design, manufacturing, and testing
  - Management procedures (e.g. SPC, TQM)
- Continuous decreasing numbers for AOQ and failure rate
- Detailed failure analysis using 8D methodology
- Continuous improvement of quality performance of parts and technology

QUALITY GOALS AND METHODS

The goals are straightforward: customer satisfaction through continuous improvement towards zero defects in every area of our operation. We are committed to meet our customers' requirements in terms of quality and service. In order to achieve this, we build excellence into our product from concept to delivery and beyond.

- **Design-In Quality**

  Quality must be designed into products. Vishay uses optimized design rules based on statistical information. This is refined using electrical, thermal, and mechanical simulation together with techniques such as FMEA, QFD, and DOE.

- **Built-In Quality**

  Quality is built into all Vishay products by using qualified materials, suppliers, and processes. Fundamental to this is the use of SPC techniques by both Vishay and its suppliers. The use of these techniques, as well as tracking critical processes, reduces variability, optimizing the process with respect to the specification. The target is defect prevention and continuous improvement.

- **Qualification**

  All new products are qualified before release by submitting them to a series of mechanical, electrical, and environmental tests. The same procedure is used for new or changed processes or packages.

- **Monitoring**

  A selection of the same or similar tests used for qualification is also used to monitor the short- and long-term reliability of the product.

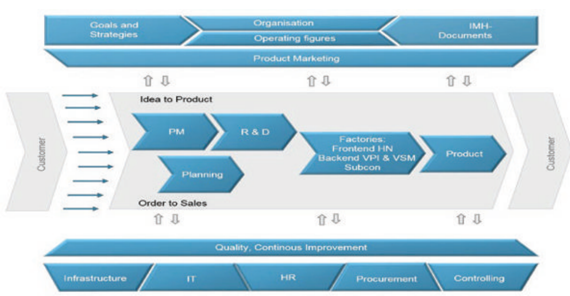
- **SPC (Statistical Process Control)**

  SPC is an essential part of all Vishay process control. It has been established for many years and is used as a tool for the continuous improvement of processes by measuring, controlling, and reducing variability.

- **Vishay Quality System**

  All Vishay's facilities worldwide are approved to ISO 9000. In addition, depending on their activities, some Vishay companies are approved to recognized international and industry standards such as IATF 16949.

Each subsidiary goal is to fulfill the particular requirements of customers. The Optoelectronic divisions of Vishay Semiconductor GmbH are certified according to IATF 16949.



The procedures used are based upon these standards and laid down in an approved and controlled quality manual.

BUSINESS EXCELLENCE

Total quality management is a management system combining the resources of all employees, customers, and suppliers in order to achieve total customer satisfaction. The fundamental elements of this system are:

- Management commitment
- EFQM assessment methodology
- Employee involvement teams (EITs)
- Supplier development and partnership
- Quality tools
- Training
- Quality system
- Design for Six Sigma
- Think Automotive Quality program
- Zero defect

All Vishay employees from the senior management downwards are trained in understanding and use of TQM. Every employee plays its own part in the continuous improvement process which is fundamental to TQM and our corporate commitment to exceed customers' expectations in all areas including design, technology, manufacturing, human resources, marketing, and finance. Everyone is involved in fulfilling this goal. The management believes that this can only be achieved by employee empowerment.

The Vishay corporate core values

- Leadership by example
- Employee empowerment
- Continuous improvement
- Total customer satisfaction

are the very essence of the Vishay quality movement process.

- **Training**

Vishay maintains that it can only realize its aims if the employees are well trained. It therefore invests heavily in courses to provide all employees with the knowledge they need to facilitate continuous improvement. A training profile has been established for all employees with emphasis being placed on Total Quality Leadership. Our long-term aim is to continuously improve our training so as to keep ahead of projected changes in business and technology.

TQM TOOLS

As part of its search for excellence, Vishay employs many different techniques and tools. The most important of them are:

- **Auditing**

As well as third party auditing employed for approval by ISO 9000 and customers, Vishay carries out its own internal and external auditing. There is a common auditing procedure for suppliers and sub-contractors between the Vishay entities. This procedure is also used for inter-company auditing between the facilities within Vishay. It is based on the "Continuous Improvement" concept with heavy emphasis on the use of SPC and other statistical tools for the control and reduction of variability.

Internal audits are carried out on a routine basis. They include audits of satellite facilities (i.e., sales offices, warehousing etc.). Audits are also used widely to determine attitudes and expectations both within and outside the company.

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- **Failure Mode and Effect Analysis (FMEA)**

FMEA is a technique for analyzing the possible methods of failure and their effect upon the performance / reliability of the product / process. Process FMEAs are performed for all processes. In addition, product FMEAs are performed on all critical or customer products.

- **Design of Experiments (DOE)**

There is a series of tools that may be used for the statistical design of experiments. It consists of a formalized procedure for optimizing and analyzing experiments in a controlled manner. Taguchi and factorial experiment design are included in this. They provide a major advantage in determining the most important input parameters, making the experiment more efficient and promoting common understanding among team members of the methods and principles used.

- **Gauge Repeatability and Reproducibility (GR and R)**

This technique is used to determine equipment's suitability for purpose. It is used to make certain that all equipment is capable of functioning to the required accuracy and repeatability. All new equipment is approved before use by this technique.

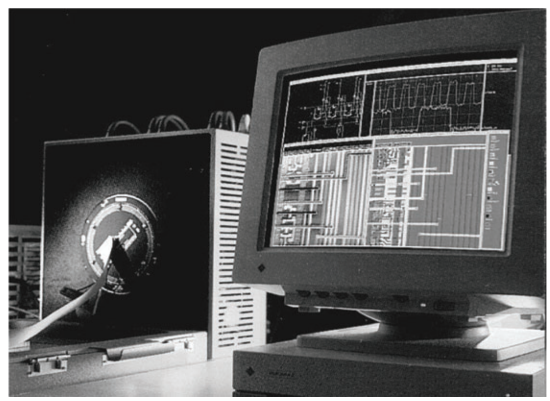
- **Quality Function Deployment (QFD)**

QFD is a method for translating customer requirements into recognizable requirements for Vishay's marketing, design, research, manufacturing, and sales (including after-sales). QFD is a process, which brings together the life cycle of a product from its conception, through design, manufacture, distribution, and use until it has served its expected life.

QUALITY SERVICE

Vishay believes that quality of service is equally as important as the technical ability of its products to meet their required performance and reliability. Our objectives therefore include:

- On-time delivery
- Short response time to customers' requests
- Rapid and informed technical support
- Fast handling of complaints
- A partnership with our customers



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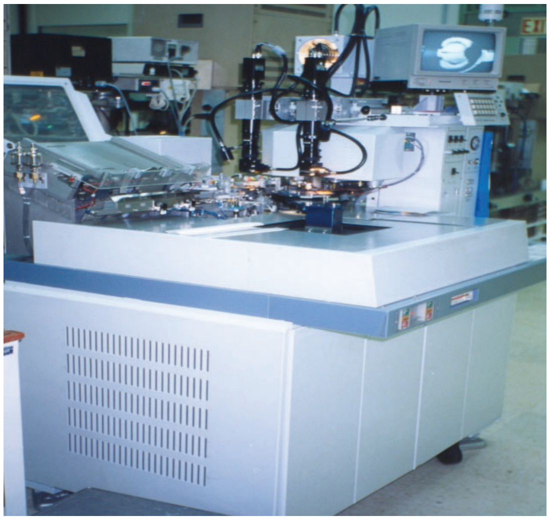
- **Customer Quality**

Complaints fall mainly into two categories:

- Logistical
- Technical

Vishay has a procedure detailing the handling of complaints. Initially complaints are forwarded to the appropriate sales office where in-depth information describing the problem, using the Vishay customer analysis request (CAR), is of considerable help in giving a fast and accurate response. If it is necessary to send back the product for logistical reasons, the sales office issues a returned material authorization (RMA) number.

On receipt of the goods in good condition, credit is automatically issued.



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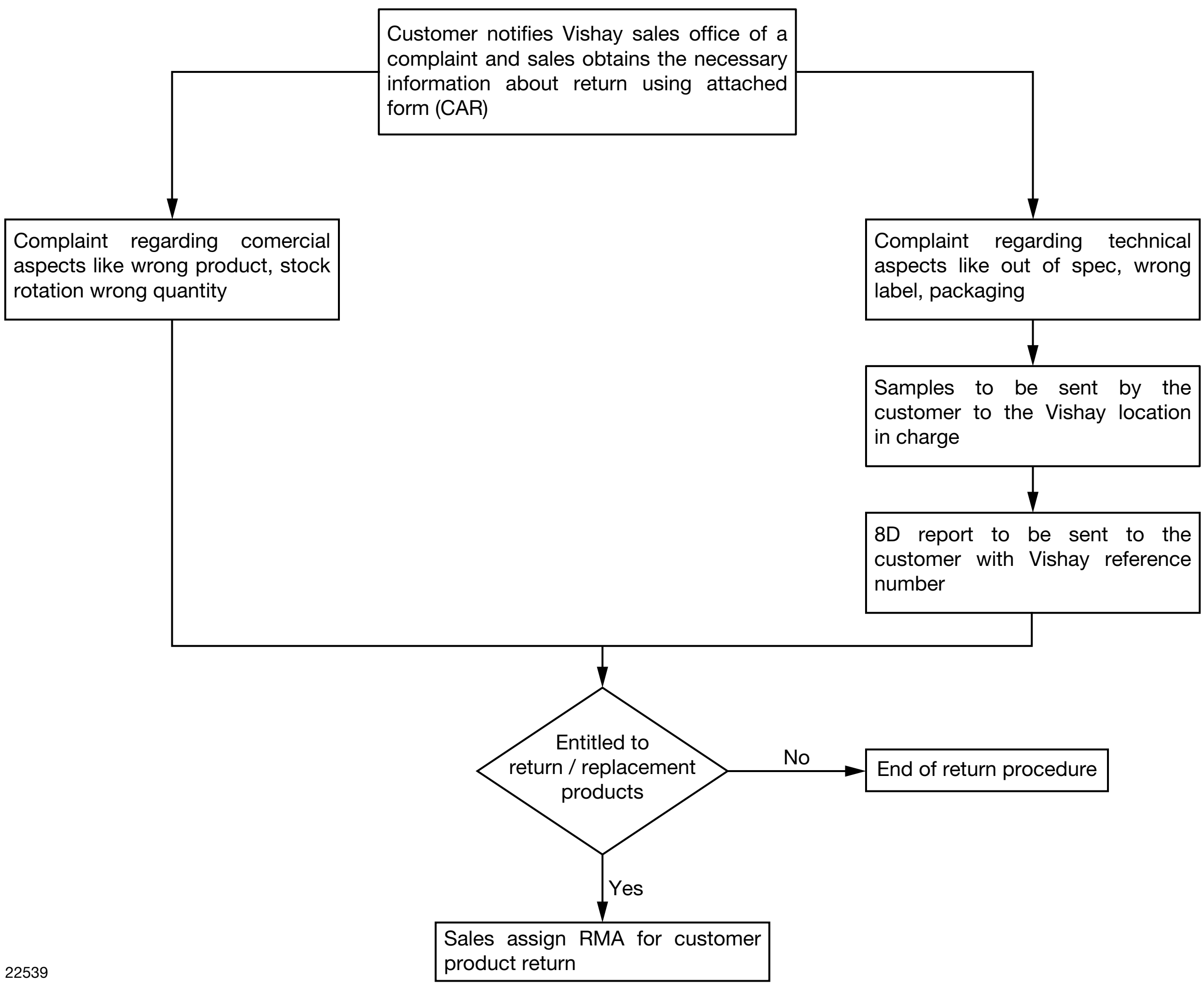
If there is a technical reason for complaint, a sample together with the **CAR** is sent to the sales office for forwarding to the failure analysis department of the supplying facility. The device's receipt will be acknowledged and a report issued on completion of the analysis. The cycle time for this analysis has set targets and is constantly monitored in order to improve the response time. Failure analysis normally consists of electrical testing, functional testing, mechanical analysis (including X-ray), decapsulation, visual analysis and electrical probing. Other specialized techniques (i.e. LCD, thermal imaging, SEM, acoustic microscopy) may be used if necessary.

If the analysis uncovers a quality problem, a corrective action report (CAR) in 8D format will be issued. Any subsequent returns are handled with the RMA procedure.



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Complaint and Return Procedure

CORRECTIVE ACTION REQUEST

CS Group **Ref**: *CS Group* -xxxxx

Customer Information

Customer	:	____
Contact Person	:	____
Tel No.	:	____
Email Address	:	____
Cust. Ref. No.	:	____
Cust. Location	:	____

Vishay Information

Vishay Originator	:	____
Date Vishay 1st Rec'd	:	____
Date Sent to Mfg Site	:	____
Sent to	:	____
Sales/CS Contact	:	____
AWB #	:	____

Device Information

Vishay PN	:	____	Datecode	:	____
Customer PN	:	____	Plant Code	:	____
Quantity	:	____	Lot/Serial #	:	____
Potential Return	:	____	DN/Invoice #	:	____

Defect Information

Type of Complaint
[ ] Electrical [ ] Mechanical [ ] Visual
[ ] Packing [ ] Label [ ] Mixed Part
[ ] Other:

Comments: ____

~For soldering complaint, pls attach customer's profile and solder composition~

Point of Defect
[ ] Qualification [ ] Incoming [ ] Line/Assembly
[ ] Field/Warranty Defect *(How long has the product been in use?)*: ____
[ ] Reliability: [ ] 0km/Car Plant Assembly (for automotive)

Comments: ____

~Please note any important test, process, or usage conditions~

Defect Rate : ____
Application : ____
Remarks/Other Data : ____

Notes:
1. Please attach a copy of the reel label.
2. Please take precaution against ESD and mechanical damage when forwarding samples.

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Corrective **A**ction **R**equest Form

VISHAY

Facility address (line 1)
Facility address (line 2)
Facility address (line 3)
Facility phone number

CAR Number:	
Page:	1
Report Date:	

VISHAY *Division Name*
8D Report

Complete for all applicable items:

Date Opened:		Originator:		*Division Specific Information*	
Vishay Location:		Vishay Part No.:			
Customer:		Date Code:		Customer Contact:	
Customer Location:		Device Type:		Failure Status:	
Customer Ref. Code:		Value:		Quantity Returned:	
Customer Part No.:		Tolerance:		Vishay Lot Number:	
Customer P.O. No.:		RMA Number:		Date of Assembly:	
Analysis Code:		Package Type:		Delivery Number:	

8D APPROACH – Disciplines 1, 2, and 4 below must be completed for ALL requests.

DISCIPLINE 1: ESTABLISH TEAM

Team Leader (and position):

Team Members (and positions):

DISCIPLINE 2: DESCRIBE PROBLEM

Customer Information:

Vishay Information:

DISCIPLINE 3: CONTAINMENT ACTIONS

Containment Actions and Projected Completion Dates:
Vishay Process / Warehouse / Consignment locations / Vishay Sample Service Center:
Other inventory:

Containment Action Verification Data (table, graph, etc…) and/or Plan:

Product/Package Identification for Contained Material:

DISCIPLINE 4: ROOT CAUSE / RESULTS

Process Root Cause:

Escape Root Cause:

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Company Confidential Information

Vishay 8D Form

VISHAY

Facility address (line 1)
Facility address (line 2)
Facility address (line 3)
Facility phone number

CAR Number:	
Page:	2
Report Date:	

VISHAY *Division Name*
8D Report

If VALID, ALL Disciplines must be completed.

DISCIPLINE 5: CORRECTIVE ACTIONS

Process Root Cause Corrective Action:

Escape Root Cause Corrective Action:

DISCIPLINE 6: IMPLEMENT CORRECTIVE ACTIONS

Corrective Action Projected Completion Dates:

Corrective Action Verification Data (table, graph, etc...) and/or Plan:

DISCIPLINE 7: PREVENT RECURRENCE

Update Standards:

Document Type	Required (Yes/No)	Document #	Who	When
Control Plan				
FMEA				
PM Plan				
Procedure(s)				
Test Program				
Drawings				
BOM				
Other				

Look Across (Corrective Actions applied to other areas to prevent recurrence):

Type	Required (Yes/No)	Who	When	Details (e.g. family, equipment, location names)
Product Families				
Manufacturing Lines				
Equipment				
Other Locations				

DISCIPLINE 8: CONGRATULATE TEAM

Revised by:		Revision:		Date:	
Approved by:		Date:		Date Closed:	

Irrespective of the use of terms in this form it does not include neither expressly not implied any statement to contractual or statutory claims for compensation. It neither contains nor constitutes directly or indirectly any kind of acknowledgement of fault or of claims of whatever nature

CQA004, Attachment II: 21 October 2013

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Company Confidential Information

Vishay 8D Form

Change Notification

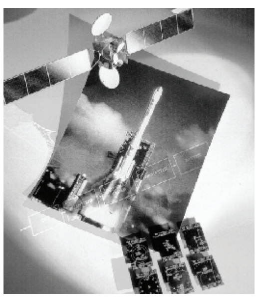
All product and process changes are controlled and released via ATP (approval of technical product and process changes). This requires the approval of the relevant departments. In the case of a major change, the change is forwarded to customers via sales / marketing before implementation. Where specific agreements are in place, the change will not be implemented unless approved by the customer.

QUALITY AND RELIABILITY

ASSURANCE PROGRAM

Though both quality and reliability are designed into all Vishay products, three basic programs must assure them:

- Average outgoing quality (AOQ) - 100 % testing is followed by sample testing to measure the defect level of the shipped product. This defect level (AOQ) is measured in ppm (parts per million)
- Reliability qualification program - to assure that the design, process, or change is reliable
- Reliability monitoring program - to measure and assure that there is no decrease in the reliability of the product



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AOQ PROGRAM

Before leaving the factory, all products are sampled after 100 % testing to ensure that they meet a minimum quality level and to measure the level of defects. The results are accumulated and expressed in ppm (parts per million). They are the measure of the average number of potentially failed parts in deliveries over a period of time. The sample size used is determined by AQL or LTPD tables depending upon the product. No rejects are allowed in the sample.

The AOQ value is calculated monthly using the method defined in standard JEDEC® 16:

$$AOQ = p \times LAR \times 10^6 \text{ (ppm)}$$

where:

$$p = \frac{\text{number of devices rejected}}{\text{total number of devices tested}}$$

= lot acceptance rate:

$$LAR = 1 - \frac{\text{number of lots rejected}}{\text{number of lots tested}}$$

The AOQ values are recorded separately with regard to electrical and mechanical (visual) rejects by product type and package.

RELIABILITY AND QUALIFICATION

Qualification is used as a means of verifying that a new product or process meets specified reliability requirements. This is also used to verify and release changes to products or processes including new materials, packages, and manufacturing locations. At the same time it provides a means to obtain information on the performance and reliability of new products and technologies.

There are three types of qualification and release:

- Wafer process / technology qualification
- Package qualification
- Product / device qualification

The actual qualification procedure depends on which of these (or combinations of these) are to be qualified. Normally there are three categories of qualification in order of degree of qualification and testing required.

For the qualification there are two different standards. For Commodity and Industrial products the Vishay internal standard is used. For Vishay Automotive Grade parts, the qualification is done according to AEC-Q101.

Accelerated testing is normally used in order to produce results fast. The stress level employed depends upon the failure mode investigated. The stress test is set so that the level used gives the maximum acceleration without introducing any new or untypical failure mode.

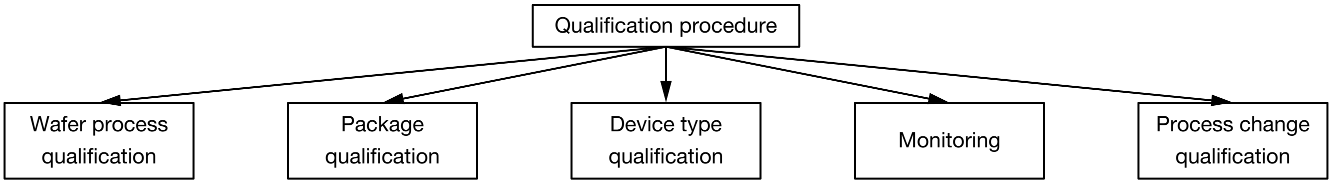
The tests used consist of a set of the following:

- High temperature life test (static)
- High temperature life test (dynamic)
- HTRB (high temperature reverse bias)
- Humidity 85/85 (with or without bias)
- Temperature cycling
- High temperature storage
- Low temperature storage
- Marking permanency
- Lead integrity
- Solderability
- Resistance to solder heat
- Mechanical shock (not plastic packages)
- Vibration (not plastic packages)
- ESD characterization

SMD devices only are subjected to pre-conditioning to simulate board assembly techniques using the methods defined in standard J-STD-020D before being subjected to stresses.

Normally, the endpoint tests are related to the datasheet or to specified parameters. Additionally, they may include:

- Destructive physical analysis
- X-ray
- Delamination testing using scanning acoustic microscope
- Thermal imaging
- Thermal and electrical resistance analysis



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A summary of the reliability test results combined with process flows and technological data will be prepared when the device has passed the Vishay qualification tests. The summary is named QualPack.

For Vishay Automotive Grade devices also additional information according to the PPAP requirements will be provided on request.

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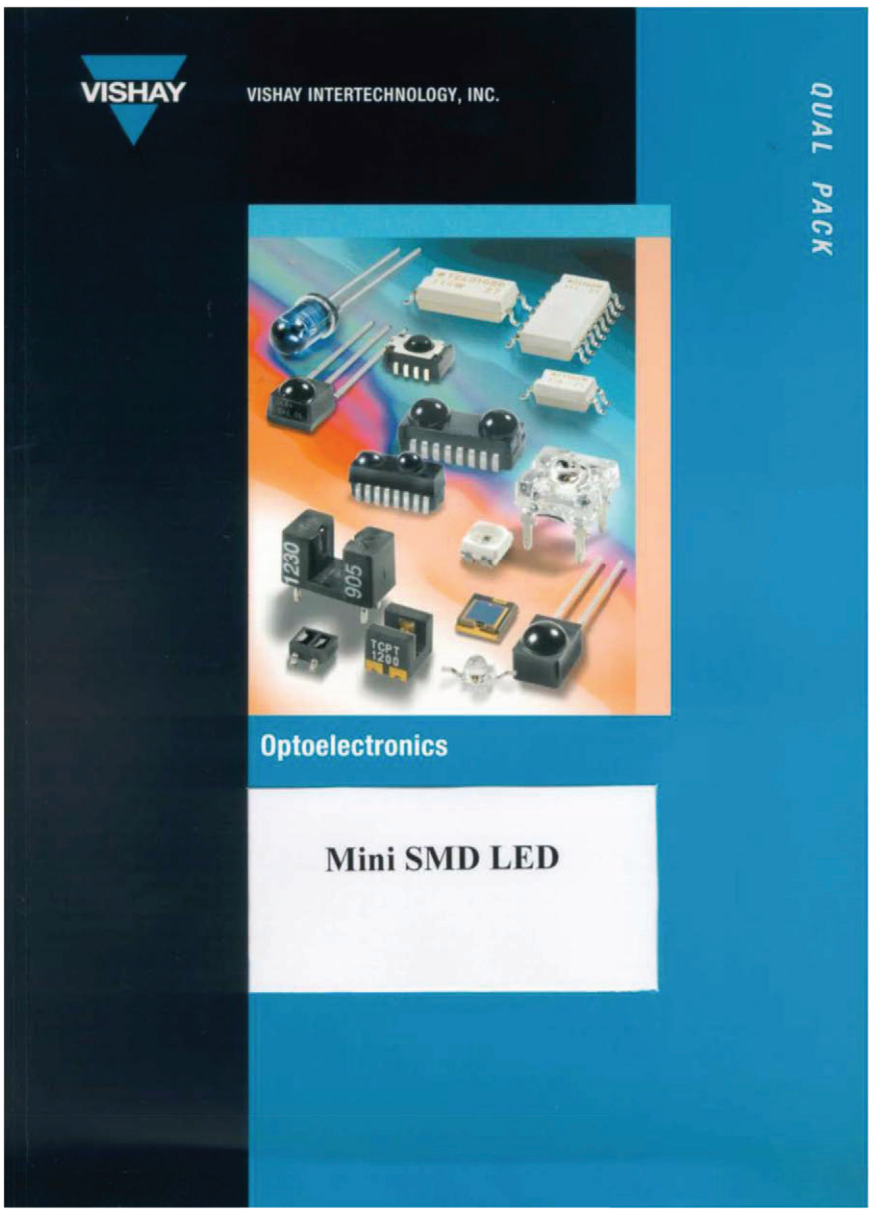


Example of the QualPack

RELIABILITY MONITORING AND WEAR-OUT

The monitoring program consists of short-term monitoring to provide fast feedback on a regular basis in case of a reduction in reliability and to measure the early-life failure rate (EFR). At the same time, long-term monitoring is used to determinate the long-term steady-state failure rate (LFR). The tests used are a subset from those used for qualification and consist of:

- Life tests
- Humidity tests
- Temperature-cycling tests

The actual tests used depend on the product tested.

Depending on the assembly volume a yearly monitoring and wear-out test plan is created.

Wear-out data are very important in optoelectronic device.

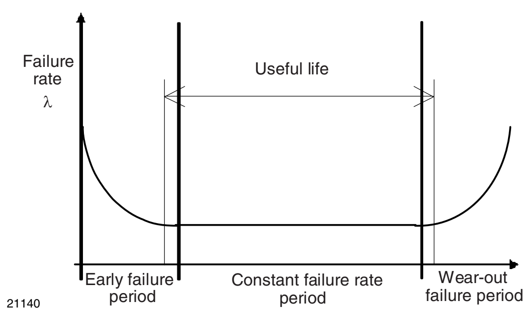


Fig. 3 - Bathtub Curve

The lifetime distribution curve is shown on Fig. 3. This curve is also known as the “bathtub curve” because of its shape. There are three basic sections:

- Early-life failures (infant mortality)
- Operating-life failures (random failures)
- Wear-out failures

Out of that data degradation curves can be made. These curves show the long time behavior of the different devices.

Some typical curves are attached in this report.

RELIABILITY PRINCIPLES

Reliability is the probability that a part works operated, under specific conditions, performs properly for a given period of time.

$$F(t) + R(t) = 1 \quad \text{or} \quad R(t) = 1 - F(t)$$

where:

R(t) = probability of survival

F(t) = probability of failure

$F(t) = 1 - e^{-\lambda t}$

where

λ = instantaneous failure rate

t = time

thus,

$$R(t) = e^{-\lambda t}$$

MTTF, MTBF

MTTF (mean time to failure) applies to parts that will be thrown away on failing. MTBF (mean time between failures) applies to parts or equipment that is going to be repaired. MTTF is the inverse failure rate.

$$MTTF = \frac{1}{\lambda}$$

So R(t) becomes to:

$$R(t) = e^{-\lambda t} = e^{-\frac{t}{MTTF}}$$

After a certain time, t will be equal to MTTF, R(t) becomes:

$$R(t) = e^{-1} = 0.37$$

If a large number of units are considered, only 37 % of their operation times will be longer than MTTF figure.

The failure rate (λ) during the constant (random) failure period is determined from life-test data. The failure rate is calculated from the formula:

$$\lambda = \frac{r}{\Sigma(f_i \times t_i) + (N \times t)} = \frac{r}{C}$$

where

λ = failure rate (h^{-1})

r = number of observed failures

f_i = failure number

t_i = time to defect

N = good sample size

t = entire operating time

C = number of components x h

The result is expressed in either

a) % per 1000 component hours by multiplying by 10^5

or in

b) FITs by multiplying by 10^9 (1 FIT = 10^{-9} h^{-1})

Example 1: determination of failure rate λ

500 devices were operated over a period of 2000 h (t) with: 1 failure (f_1) after 1000 h (t_1)

The failure rate of the given example can be calculated as follows:

$$\lambda = \frac{1}{(1 \times 1000\ h) + (499 \times 2000\ h)}$$

$$\lambda = 1.001 \times 10^{-6} h^{-1}$$

That means that this sample has an average failure rate of **0.1 %/1000 h or 1001 FIT**

Example 2: the failure rate of the population

Using example 1 with a failure rate of 1001 FIT and 1 failure: $\chi^2/2$ at 60 % confidence is 2.02

$$\lambda_{pop} = \frac{2.02}{9.99 \times 10^5} = 2022\ FIT$$

This means that the failure rate of the population will not exceed 2022 FIT with a probability of 60 %.

Observed failure rates as measured above are for the specific lot of devices tested. If the predicted failure rate for the total population is required, statistical confidence factors have to be applied.

The confidence factors can be obtained from “chi square” (χ^2) charts. Normally, these charts show the value of (χ^2/2) rather than χ^2. The failure rate is calculated by dividing the χ^2/2 factor by the number of component hours.

$$\lambda_{pop} = \frac{(\chi^2/2)}{C}$$

The values for χ^2/2 are given in table 1

TABLE 1 - χ^2/2 CHART

NUMBER OF FAILURES	CONFIDENCE LEVEL	
	60 %	90 %
0	0.92	2.31
1	2.02	3.89
2	3.08	5.30
3	4.17	6.70
4	5.24	8.00
5	6.25	9.25
6	7.27	10.55

- **Accelerated Stress Testing**

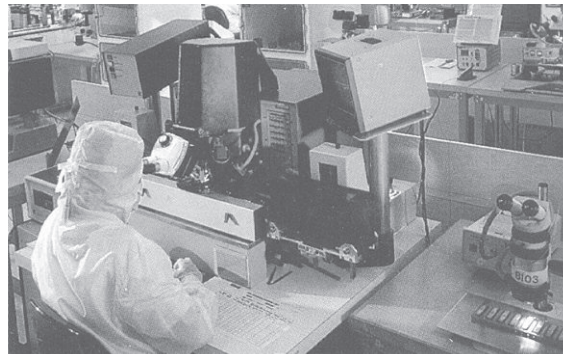
In order to be able to assure long operating life with a reasonable confidence, Vishay carries out accelerated testing on all its products. The normal accelerating factor is the temperature of operation. Most failure mechanisms of semiconductors are dependent upon temperature. This temperature dependence is best described by the Arrhenius equation.

$$\lambda_{T_2} = \lambda_{T_1} \times e^{\left[\frac{E_A}{k} \times \left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]}$$

where

k = Boltzmann’s constant 8.63 x 10^{-5} eV/K
E_A = activation energy (eV)
T_1 = operation temperature (K)
T_2 = stress temperature (K)
λ_{T_1} = operation failure rate
λ_{T_2} = stress-test failure rate

Using this equation, it is possible from the stress test results to predict what would happen in use at the normal temperature of operation.



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ACTIVATION ENERGY

Provided the stress testing does not introduce a failure mode, which would not occur in practice, this method gives an acceptable method for predicting reliability using short test periods compared to the life of the device. It is necessary to know the activation energy of the failure mode occurring during the accelerated testing. This can be determined by experiment. In practice, it is unusual to find a failure or if there is, it is a random failure mode. For this reason an average activation energy is normally used for this calculation. Though activation energies can vary between 0.3 eV and 2.2 eV, under the conditions of use, activation energies of between 0.6 eV and 0.9 eV are used depending upon the technology.

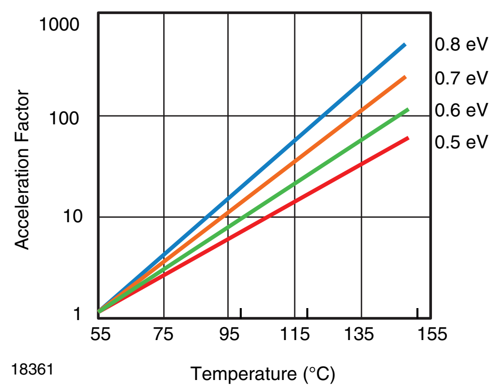

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Fig. 4 - Acceleration Factor for different Activation Energies Normalized to T = 55 °C

ACTIVATION ENERGIES FOR COMMON FAILURE MECHANISMS

The activation energies for some of the major semiconductor failure mechanisms are given in the table below. These are estimates taken from published literature.

TABLE 2 - ACTIVATION ENERGIES FOR COMMON FAILURE MECHANISM	
FAILURE MECHANISM	**ACTIVATION ENERGY**
Mechanical wire shorts	0.3 to 0.4
Diffusion and bulk defects	0.3 to 0.4
Oxide defects	0.3 to 0.4
Top-to-bottom metal short	0.5
Electro migration	0.4 to 1.2
Electrolytic corrosion	0.8 to 1.0
Gold-aluminum intermetallics	0.8 to 2.0
Gold-aluminum bond degradation	1.0 to 2.2
Ionic contamination	1.02
Alloy pitting	1.77

Failure rates are quoted at an operating temperature of 55 °C and 60 % confidence using an activation energy (E_A) of 0.8 eV for optoelectronic devices.

Example 3: conversion to 55 °C
In Example 2, the life test was out at 125 °C so to transform to an operating temperature of 55 °C.

$T_1 = 273 + 55 = 328 \text{ K}$
$T_1 = 273 + 125 = 398 \text{ K}$
Acceleration factor =

$$\frac{\lambda_{(T_2)}}{\lambda_{(T_1)}} = \frac{\lambda_{(423\text{ K})}}{\lambda_{(328\text{ K})}} = 144$$

thus

$$\lambda_{(328\text{ K})} = \frac{\lambda_{(423\text{ K})}}{144} = \frac{2022}{144}$$

= 14

FIT (at 55 °C with a confidence of 60 %)
This figure can be re-calculated for any operating / junction temperature using this method.

- **EFR (Early Life Failure Rate)**

This is defined as the proportion of failures that will occur during the warranty period of the system for which they were designed. In order to standardize this period, Vishay uses 1000 operation hours as the reference period. This is the figure also used by the automotive industry; it equates to one year in the life of an automobile. In order to estimate this figure, Vishay normally operates a sample of devices for 48 h or 168 h under the accelerated conditions detailed above. The Arrhenius law is then used as before to calculate the failure rate at 55 °C with a confidence level of 60 %. This figure is multiplied by 1000 to give the failures in 1000 h and by 10^6 to give a failure in ppm. All EFR figures are quoted in ppm (parts per million).

The value of EFR and LFR is also depending on the amount of new products brought to market in the period. If a lot of new products are released the EFR and the LFR value can also be increased in that period due to increased rejects.

- **Climatic Tests Models**

Temperature cycling failure rate

The inverse power law is used to model fatigue failures of materials that are subjected to thermal cycling. For the purpose of accelerated testing, this model relationship is called Coffin-Manson relationship, and can be expressed as follows:

$$A_F = \left(\frac{\Delta T_{stress}}{\Delta T_{use}}\right)^M$$

where:

A_F = acceleration factor
ΔT_{use} = temp. range under normal operation
ΔT_{stress} = temp. range under stress operation
M = constant characteristic of the failure mechanism

TABLE 3 - COFFIN - MANSON EXPONENT M	
FAILURE MECHANISM	**M**
Al wire bond failure	3.5
Intermetallic bond fracture	4.0
Au wire bond heel crack	5.1
Chip-out bond failure	7.1

For instance:

ΔT_{use} = 15 °C/60 °C = 45 °C
ΔT_{stress} = -25 °C/100 °C = 125 °C

$$A_F = \left(\frac{125\text{ °C}}{45\text{ °C}}\right)^3 \approx 21$$

Relative Humidity failure rate

Moisture effect modeling is based upon the Howard-Pecht-Peck model using the acceleration factor of the equation shown below:

$$A_F = \left(\frac{RH_{stress}}{RH_{use}}\right)^C \times e^{\left[\frac{E_A}{k}\left(\frac{1}{T_{use}} - \frac{1}{T_{stress}}\right)\right]}$$

where:

RH_{stress} = relative humidity during test
RH_{use} = relative humidity during operation
T_{stress} = temperature during test
T_{use} = temperature during operation
E_A = activation energy
k = Boltzmann constant
C = material constant

For instance:

RH_{stress} = 85 %, RH_{use} = 92 %
T_{stress} = 85 °C, T_{use} = 40 °C

$$A_F = \left(\frac{85\text{ \% RH}}{92\text{ \% RH}}\right)^3 \times e^{\left[\frac{0.8}{8.617 \times 10^{-5}}\left(\frac{1}{313} - \frac{1}{358}\right)\right]}$$

$A_F \approx 33$

This example shows how to transform test conditions into environmental or into another test conditions. This equation is applicable for devices subjected to temperature humidity bias (THB) testing.

Using these acceleration factors the useful lifetime can be calculated. Applying the acceleration factor once more, useful lifetime for the moisture effect model for parts subjected to THB can be estimated by the following equation:

$$\text{Useful life}_{\text{years}} = \frac{A_F \times \text{test hours}}{\text{hours per year}}$$

with:

test hours = 1000 hours per year = 8760

$A_F \approx 118$ (40 °C / 60 % RH)

$$\text{Useful life}_{\text{years}} = \frac{118 \times 1000}{8760} \approx 13.5 \text{ years}$$

This means that operation in 40 °C / 60 % RH environment is good for around 13 years, calculated out of the 85 °C / 85 % RH 1000 h humidity stress test.

HANDLING FOR QUALITY

- **Electrostatic Discharge (ESD) Precautions**

Electrostatic discharge is defined as the high voltage, which is generated when two dissimilar materials move in contact with one another. This may be by rubbing (i.e. walking on a carpet) or by hot air or gas passing over an insulated object. Sometimes, ESD is easily detectable as when a person is discharged to ground.

Electronic devices may be irreversibly damaged when subjected to this discharge. They can also be damaged if they are charged to a high voltage and then discharged to ground.

Damage due to ESD may occur at any point in the process of manufacture and use of the device. ESD is a particular problem if the humidity is low (< 40 %) which is very common in non-humidified but air-conditioned buildings. ESD is not just generated by the human body but can also occur with ungrounded machinery.

ESD may cause a device to fail immediately or damage a device so that it will fail later. Whether this happens or not, usually depends on the energy available in the ESD pulse.

All ESD-sensitive Vishay products are protected by means of

- Protection structures on chip
- ESD protection measures during handling and shipping

Vishay has laid down procedures, which detail the methods to be used for protection against ESD. These measures meet or exceed the standards for ESD-protective and preventative measures.

These include the use of:

- Earthen wrist straps and benches
- Conductive floors
- Protective clothing
- Controlled humidity

It also lays down the methods for routinely checking these and other items such as the earthen of machines.

A semiconductor device is only completely protected when enclosed in a “Faraday Cage”. This is a completely closed conductive container (i.e., sealed conductive bag or box).

Most packaging material (i.e. tubes) used for semiconductors is now manufactured from anti-static material or anti-static-coated material. This does not mean that the devices are completely protected from ESD, only that the packing will not generate ESD. Devices are completely protected only when surrounded on all sides by a conductive package.

It should also be remembered that devices can equally as easily be damaged by discharge from a high voltage to ground as vice-versa.

Testing for ESD resistance is part of the qualification procedure. The methods used are detailed in MIL-STD-883 Method 3015.7 (human body model) and EOS/ESD-S5.1-1993 (machine model) specification. Also testing according to the CDM (charged coupled device model) is part of the advanced qualification procedure.

- **Soldering**

All products are tested to ascertain their ability to withstand the industry standard soldering conditions after storage. In general, these conditions are as follows:

- Wave soldering: double-wave soldering according to CECC 00802
- Reflow soldering: according to JEDEC-STD-20

Note

- Certain components may have limitations due to their construction

- **Dry pack**

When being stored, certain types of device packages can absorb moisture, which is released during the soldering operations, thus causing damage to the device. The so-called “popcorn” effect is such an example. To prevent this, surface-mount devices (SMD) are evaluated during qualification, using a test consisting of moisture followed by soldering simulation (pre-conditioning) and then subjected to various stress tests. In table 4 - Moisture Sensitivity Levels - the six different levels, the floor life conditions as well as the soak requirements belonging to these levels are described. Any device which is found to deteriorate under these conditions is packaged in “dry pack”.

The dry-packed devices are packed generally according to IPC JEDEC-STD-33 “Handling, Packing, Shipping, and use of Moisture / Reflow Sensitive Surface-Mount Devices”, IPC-SM-786 “Recommended Procedures for Handling of Moisture Sensitive Plastic IC Packages”.

Following some general recommendations:

- Shelf life in the packaging at < 40 °C and 90 % RH is 12 months
- After opening, the devices should be handled according to the specifications mentioned on the dry-pack label
- If the exposure or storage time is exceeded, the devices should be baked:
  - Low temperature baking - 192 h at 40 °C and 5 % RH
  - High temperature baking - 24 h at 125 °C

TABLE 4 - MOISTURE SENSITIVITY LEVELS

	FLOOR LIFE		SOAK REQUIREMENTS			
LEVEL	CONDITIONS	TIME	TIME (h)			CONDITIONS
1	≤ 30 °C / 90 % RH	Unlimited	168			85 °C / 85 % RH
2	≤ 30 °C / 60 % RH	1 year	168			85 °C / 60 % RH
2a	≤ 30 °C / 60 % RH	4 weeks	696			30 °C / 60 % RH
			X	Y	Z	
3	≤ 30 °C / 60 % RH	168 h	24	168	192	30 °C / 60 % RH
4	≤ 30 °C / 60 % RH	72 h	24	72	96	30 °C / 60 % RH
5	≤ 30 °C / 60 % RH	48 h	24	48	72	30 °C / 60 % RH
5a	≤ 30 °C / 60 % RH	24 h	24	24	48	30 °C / 60 % RH
6	≤ 30 °C / 60 % RH	6 h	0	6	6	30 °C / 60 % RH

X = default value of semiconductor manufacturer manufacturer's exposure time (MET) between bake and bag plus the maximum time allowed out of the bag at the distributor's facility. The actual times may be used rather than the default times, but they must be used if they exceed the default times.

Y = floor life of package after it is removed from dry pack bag.

Z = total soak time for evaluation (X + Y).

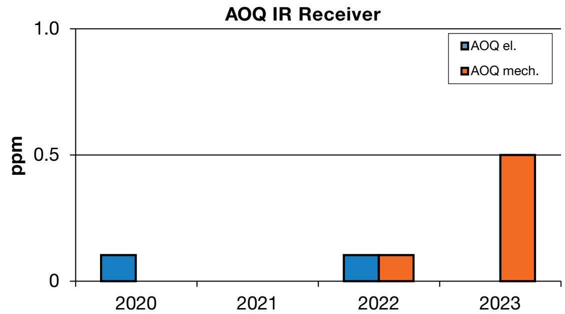
Note

- There are two possible floor lives and soak times in level 5. The correct floor life will be determined by the manufacturer and will be noted on the dry pack bag label per JEP 113. "Symbol and Labels for Moisture Sensitive Devices"

OUTGOING QUALITY AND FIT RATE (IR RECEIVER)

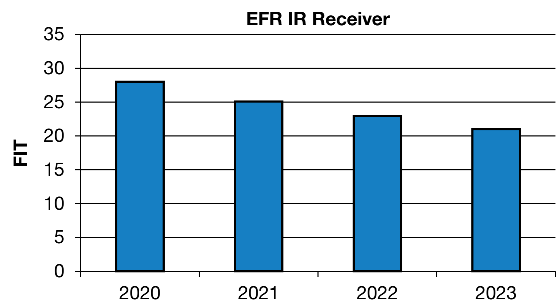
AOQ (Average Outgoing Quality)

The AOQ is measured following 100 % test by sampling the outgoing product. The results of this inspection are recorded in ppm (parts per million) using the method defined in JEDEC 16. The figures below cover the last year for both the subject and structurally similar products.



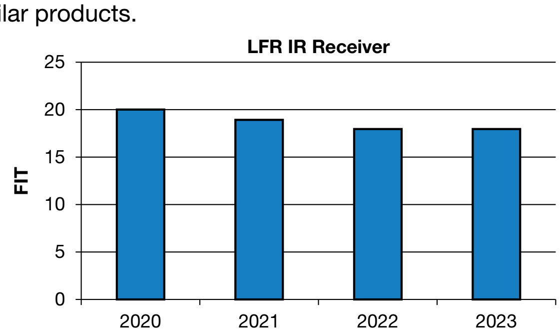
EFR (Early Failure Rate)

The EFR is measured on a sample of devices by operating them at an elevated temperature and measuring the number which fail to meet specification after 48 hours. The figure is expressed in terms of FIT.



LFR (Latent Failure Rate)

The LFR is measured by operating devices at elevated temperatures for a minimum of 1000 hours and measuring the failure rate. Using the Arrhenius law the expected failure rate at a junction temperature T_j = 55 °C is calculated using an activation energy of 0.8 eV with a confidence level of 60 %. This is expressed in units of 10^9 hours (FITs). The figures given are for the subject product and structurally similar products.



MTTF (Mean Time To Failure for Functional Defects) Based on 2023 Data

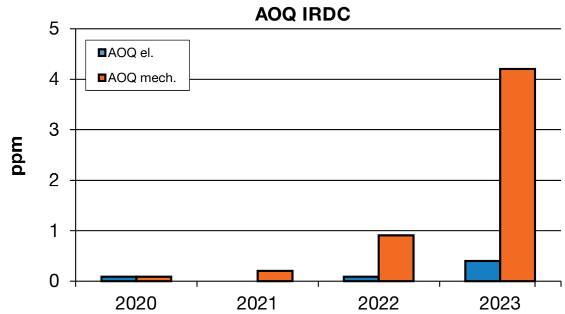
Actual MTTF values for: CL = 60 %; EA = 0.8 eV

TEMPERATURE (°C)	MTTF (mio. hours)	DEVICE FAILURE RATE (%/1000 hours)	LFR (FIT)
25	941.49	0.00011	1
55	54.64	0.00183	18
85	5.11	0.01958	196
100	1.880	0.05550	555
110	0.94	0.10624	1062
125	0.38	0.26468	2647

OUTGOING QUALITY AND FIT RATE (IRDC)

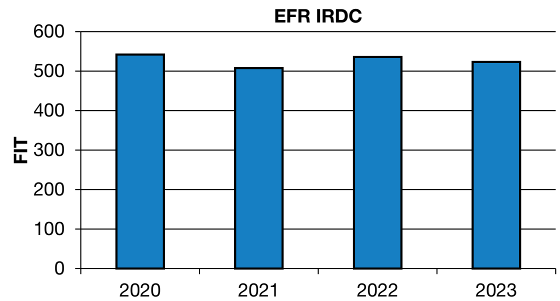
AOQ (Average Outgoing Quality)

The AOQ is measured following 100 % test by sampling the outgoing product. The results of this inspection are recorded in ppm (parts per million) using the method defined in JEDEC 16. The figures below cover the last year for both the subject and structurally similar products.



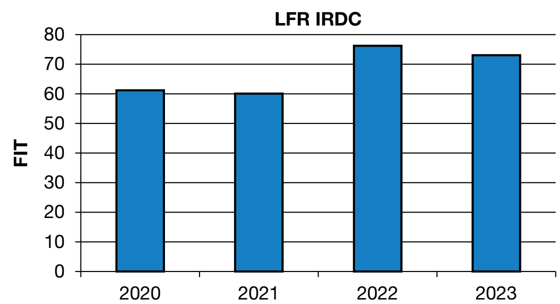
EFR (Early Failure Rate)

The EFR is measured on a sample of devices by operating them at an elevated temperature and measuring the number which fail to meet specification after 48 hours. The figure is expressed in terms of FIT.



LFR (Latent Failure Rate)

The LFR is measured by operating devices at elevated temperatures for a minimum of 1000 hours and measuring the failure rate. Using the Arrhenius law the expected failure rate at a junction temperature T_j = 55 °C is calculated using an Activation Energy of 0.8 eV with a confidence level of 60 %. This is expressed in units of 10^9 hours (FITs). The figures given are for the subject product and structurally similar products.



MTTF (Mean Time To Failure for Functional Defects) Based on 2023 Data

Actual MTTF values for: CL = 60 %; EA = 0.8 eV

TEMPERATURE (°C)	MTTF (mio. hours)	DEVICE FAILURE RATE (%/1000 hours)	LFR (FIT)
25	235.53	0.00042	4
55	13.67	0.00732	73
85	1.28	0.07825	782
100	0.45	0.22183	2218
110	0.24	0.42465	4247
125	0.09	1.05800	10 580

RELIABILITY AND STATISTICS GLOSSARY

DEFINITIONS

Accelerated Life Test: a life test under conditions those are more severe than usual operating conditions. It is helpful, but not necessary, that a relationship between test severity and the probability distribution of life be ascertainable

Acceleration Factor: notation: f(t) = the time transformation from more severe test conditions to the usual conditions. The acceleration factor is f(t)/t. The differential acceleration factor is df(t)/dt

Acceptance Number: the largest numbers of defects that can occur in an acceptance sampling plan and still have the lot accepted

Acceptance Sampling Plan: an accept / reject test the purpose of which is to accept or reject a lot of items or material based on random samples from the lot

Assessment: a critical appraisal including qualitative judgments about an item, such as importance of analysis results, design criticality, and failure effect

Attribute (inspection by): a term used to designate a method of measurement whereby units are examined by noting the presence (or absence) of some characteristic or attribute in each of the units in the group under consideration and by counting how many units do (or do not) possess it. Inspection by attributes can be two kinds: either the unit of product is classified simply as defective or no defective or the number of defects in the unit of product is counted with respect to a given requirement or set of requirements

Attribute Testing: testing to evaluate whether or not an item possesses a specified attribute

Auger Electron Spectrometer: an instrument, which identifies elements on the surface of a sample. It excites the area of interest with an electron beam and observes the resultant emitted Auger electrons. These electrons have the specific characteristics of the near surface elements. It is usually used to identify very thin films, often surface contaminants

Availability (Operational Readiness): the probability that at any point in time the system is either operating satisfactorily or ready to be placed in operation on demand when used under stated conditions

Average Outgoing Quality (AOQ): the average quality of outgoing product after 100 % inspection of rejected lot, with replacement by good units of all defective units found in inspection

Bathtub Curve: a plot of failure rate of an item (whether repairable or not) vs. time. The failure rate initially decreases, then stays reasonably constant, then begins to rise rather rapidly. It has the shape of bathtub. Not all items have this behavior

Bias: (1) the difference between the s-expected value of an estimator and the value of the true parameter; (2) applied voltage

Burn-In: the initial operation of an item to stabilize its characteristics and to minimize infant mortality in the field

Confidence Interval: the interval within which it is asserted that the parameters of a probability distribution lies

Confidence Level: equals $1 - \alpha$ where α = the risk (%)

Corrective Action: a documented design, process, procedure, or materials change to correct the true cause of a failure. Part replacement with a like item does not constitute appropriate corrective action. Rather, the action should make it impossible for that failure to happen again

Cumulative Distribution Function (CDF): the probability that the random variable takes on any value less than or equal to a value x, e.g. $F(x) = CDF(x) = Pr(x \leq X)$

Defect: a deviation of an item from some ideal state. The ideal state usually is given in a formal specification

Degradation: a gradual deterioration in performance as a function of time

Derating: the intentional reduction of stress / strength ratio in the application of an item, usually for the purpose of reducing the occurrence of stress-related failures

Duty Cycle: a specified operating time of an item, followed by a specified time of no operation

Early Failure Rate: that period of life, after final assembly, in which failures occur at an initially high rate because of the presence of defective parts and workmanship. This definition applies to the first part of the bathtub curve for failure rate (infant mortality)

EDX Spectrometer: generally used with a scanning electron microscope (SEM) to provide elemental analysis of X-rays generated on the region being hit by the primary electron beam

Effectiveness: the capability of the system or device to perform its function

EOS - Electrical Overstress: the electrical stressing of electronic components beyond specifications. May be caused by ESD

ESD - Electrostatic Discharge: the transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field. Many electronic components are sensitive to ESD and will be degraded or fail

Expected Value: a statistical term. If x is a random variable and F (x) it its CDF, the E (x) = xdF (x), where the integration is over all x. For continuous variables with a pdf, this reduces to E (x) = $\int$ x pdf (x) dx. For discrete random variables with a pdf, this reduces to E (x) = $\sum x_n p(x_n)$ where the sum is over all n

Exponential Distribution: a 1-parameter distribution ($\lambda > 0$, $t \geq 0$) with: pdf (t) = λexp (- λt); Cdf (t) 0 1 - exp (-λt); Sf (t) = exp (-λt); failure rate = λ; mean time-to-failure = 1/λ. This is the constant failure-rate-distribution

Failure: the termination of the ability of an item to perform its required function

Failure Analysis: the identification of the failure mode, the failure mechanism, and the cause (i.e., defective soldering, design weakness, contamination, assembly techniques, etc.). Often includes physical dissection

Failure, Catastrophic: a sudden change in the operating characteristics of an item resulting in a complete loss of useful performance of the item

Failure, Degradation: a failure that occurs as a result of a gradual or partial change in the operating characteristics of an item

Failure, Initial: the first failure to occur in use

Failure, Latent: a malfunction that occurs as a result of a previous exposure to a condition that did not result in an immediately detectable failure. Example: latent ESD failure

Failure Mechanism: the mechanical, chemical, or other process that results in a failure

Failure Mode: the effect by which a failure is observed. Generally, describes the way the failure occurs and tells “how” with respect to operation

Failure Rate: (A) the conditional probability density that the item will fail just after time t, given the item has not failed up to time t; (B) the number of failures of an item per unit measure of life (cycles, time, miles, events, etc.) as applicable for the item

Failure, Wear-Out: any failure for which time of occurrence is governed by rapidly increasing failure rate

FIT: failure unit; (also, failures in time) failures per 10^9 h

Functional Failure: a failure whereby a device does not perform its intended function when the inputs or controls are correct

Gaussian Distribution: a 2-parameter distribution with:

$$\text{pdf}(x) = \frac{1}{\sigma\sqrt{2\pi}} \times e^{\frac{1}{2} \times \left(\frac{x - u}{\sigma}\right)^2}$$

Cdf (x) = guaf (x). SF (x) = gaufc (x). “Mean value of x” u, “standard deviation of x” = σ

Hazard Rate: instantaneous failure rate

Hypothesis, Null: a hypothesis stating that there is no difference between some characteristics of the parent populations of several different samples, i.e., that the samples came from similar populations

Infant Mortality: premature catastrophic failures occurring at a much greater rate than during the period of useful life prior to the onset of substantial wear out

Inspection: the examination and testing of supplies and services (including when appropriate, raw materials, components, and intermediate assemblies) to determine whether they conform to specified requirements

Inspection by Attributes: inspection whereby either the unit of product or characteristics thereof is classified simply as defective or no defective or the number of defects in the unit of product is counted with respect to a given requirement

Life Test: a test, usually of several items, made for the purpose of estimating some characteristic(s) of the probability distribution of life

LFR: longterm failure rate

Lot: a group of units from a particular device type submitted each time for inspection and / or testing is called the lot

Lot Reject Rate (LRR): the lot reject rate is the percentage of lots rejected form the lots evaluated

Lot Tolerance Percent Defective (LTPD): the percent defective, which is to be, accepted a minimum or arbitrary fraction of the time, or that percent defective whose probability of rejection is designated by β

Mean: (A) the arithmetic mean, the expected value; (B) as specifically modified and defined, e.g., harmonic mean (reciprocals), geometric mean (a product), logarithmic mean (logs)

Mean Life: R(t)dt; where R(t) = the s-reliability of the item; t = the interval over which the mean life is desired, usually the useful life (longevity)

Mean-Life-Between-Failures: the concept is the same as mean life except that it is for repaired items and is the mean up-time of the item. The formula is the same as for mean life except that R(t) is interpreted as the distribution of up-times. Mean-time-between-failures (MTBF): for a particular interval, the total functioning life of a population of an item divided by the total number of failures within the population during the measurement interval. The definition holds for time, cycles, miles, events, or other measure of life units

Mean-Time-To-Failure (MTTF): see “Mean Life”

Mean-Time-To-Repair (MTTR): the total corrective maintenance time divided by the total number of corrective maintenance actions during a given period of time

MTTR: = G(t)dt; where G(t) = Cdf of repair time; T - maximum allowed repair time, i.e., item is treated as no repairable at this echelon and is discarded or sent to a higher echelon for repair

Operating Characteristic (OC) Curve: a curve showing the relation between the probability of acceptance and either lot quality or process quality, whichever is applicable

Part Per Million (ppm): ppm is arrived at by multiplying the percentage defective by 10 000. Example: 0.1 % = 1000 ppm

Population: the totality of the set of items, units, measurements, etc., real or conceptual that is under consideration

Probability Distribution: a mathematical function with specific properties, which describes the probability that a random variable will take on a value or set of values. If the random variable is continuous and well behaved enough, there will be a pdf. If the random variable is discrete, there will be a pmf

Qualification: the entire process by which products are obtained from manufacturers or distributors, examined and tested, and then identified on a qualified product list

Quality: a property, which refers to, the tendency of an item to be made to specific specifications and / or the customer’s express needs. See current publications by Juran, Deming, Crosby, et al

Quality Assurance: a system of activities that provides assurance that the overall quality control job is, in fact, being done effectively. The system involves a continuing evaluation of the adequacy and effectiveness of the overall quality control program with a view to having corrective measures initiated where necessary. For a specific product or service, this involves verifications, audits, and the evaluation of the quality factors that affect the specification, production inspection, and use of the product or service

Quality Characteristics: those properties of an item or process, which can be measured, reviewed, or observed and which are identified in the drawings, specifications, or contractual requirements. Reliability becomes a quality characteristic when so defined

Quality Control (QC): the overall system of activities that provides a quality of product or service, which meets the needs of users; also, the use of such a system

Random Samples: as commonly used in acceptance sampling theory, the process of selecting sample units in such a manner that all units under consideration have the same probability of being selected

Reliability: the probability that a device will function without failure over a specified time period or amount of usage at stated conditions

Reliability Growth: reliability growth is the effort, the resource commitment, to improve design, purchasing, production, and inspection procedures to improve the reliability of a design

Risk: α: the probability of rejecting the null hypothesis falsely

Scanning Electron Microscope (SEM): an instrument, which provides a visual image of the surface features of an item. It scans an electron beam over the surface of a sample while held in a vacuum and collects any of several resultant particles or energies. The SEM provides depth of field and resolution significantly exceeding light microscopy and may be used at magnifications exceeding 50 000 times

Screening Test: a test or combination of tests intended to remove unsatisfactory items or those likely to exhibit early failures

Significance: results that show deviations between hypothesis and the observations used as a test of the hypothesis, greater than can be explained by random variation or chance alone, are called statistically significant

Significance Level: the probability that, if the hypothesis under test were true, a sample test statistic would be as bad as or worse than the observed test statistic

SPC: statistical process control

Storage Life (Shelf Life): the length of time an item can be stored under specified conditions and still meet specified requirements

Stress: a general and ambiguous term used as an extension of its meaning in mechanics as that which could cause failure. It does not distinguish between those things which cause permanent damage (deterioration) and those things, which do not (in the absence of failure)

Variance: the average of the squares of the deviations of individual measurements from their average. It is a measure of dispersion of a random variable or of data

Wear-Out: the process of attribution which results in an increase of hazard rate with increasing age (cycles, time, miles, events, etc.) as applicable for the item

ABBREVIATIONS

AQL	acceptable quality level
AOQ	average outgoing quality
CAR	corrective action report / request
DIP	dual in-line package
ECAP	electronic circuit analysis program
EFR	early failure rate
EMC	electro magnetic compatibility
EMI	electro magnetic interference
EOS	electrical overstress
ESD	electrostatic discharge
FAR	failure analysis report / request
FIT	(failure in time) failure unit; failures /10^9 h
FMEA	failure mode and effects analysis
FTA	fault tree analysis
h (t)	hazard rate
LFR	longterm failure rate
LTPD	lot tolerance percent defective
MOS	metal oxide Semiconductor
MRB	material review board
MTBF	mean-time-between-failures
MTTF	mean-time-to-failure
MTTR	mean-time-to-repair
ppm	parts per million
PRST	probability ratio sequential test
QA	quality assurance
QC	quality control
QPL	qualified products list
RPM	reliability planning and management
SCA	sneak circuit analysis
SEM	scanning electron microscope
TW	wearout time
Z (t)	hazard rate
λ	failure rate (lambda)