Electronic Design

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Know Your Safety Application Notes (Part 1): Failure Rates

This article discusses the three most common reliability prediction techniques for the failure rates of ICs and how safety application notes provide such failure-rate information.

Failure rate or base failure rate refers to the number of failures per unit of time, typically in terms of failures in time (FITs) equivalent to one failure in a billion hours, which can be expected to occur for the product during its useful lifetime. *Figure 1* shows the reliability bathtub curve model for failure of electronic components that can be divided into three sections: early life or infant mortality failures, useful life or constant (random) failures, and wear-out failures. Thus, this article focuses on failure rates during the useful life of the component.

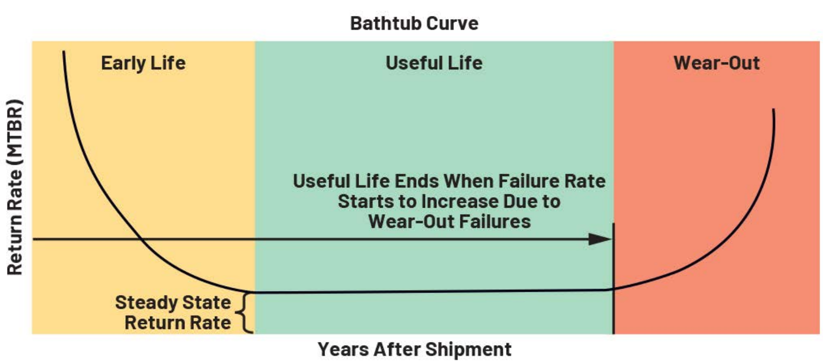
Knowing the failure rates of components in electronic systems is essential in making reliability predictions to evaluate the overall system reliability. Reliability prediction involves specifying the reliability model, the failure modes to be assumed, the diagnostic intervals, and the diagnostic coverage. These predictions serve as the input to reliability modeling techniques such as failure mode and effects analysis (FMEA), reliability block diagrams (RBDs), fault tree analysis (FTA), etc.[2,3]

In line with functional safety, the need to predict quantitative reliability related to random hardware failures of a safety-related system against the safety integrity level (SIL) targets comes from the second part of the basic functional safety standard IEC 61508.[3] It specifies the requirements for the hardware aspects of safety-related systems (SRS). Such SIL targets with respect to an SRS's probability of dangerous failure are shown in the *table*.

Safety Integrity Level Requirements with Respect to Probability of Dangerous Failure[2,3]

Safety Integrity Level	Continuous and High Demand Rate (PFH)	Low Demand Rate (PFD)
4	$\geq 10^{-9}$ to $<10^{-8}$	$\geq 10^{-5}$ to $<10^{-4}$
3	$\geq 10^{-8}$ to $<10^{-7}$	$\geq 10^{-4}$ to $<10^{-3}$
2	$\geq 10^{-7}$ to $<10^{-6}$	$\geq 10^{-3}$ to $<10^{-2}$
1	$\geq 10^{-6}$ to $<10^{-5}$	$\geq 10^{-2}$ to $<10^{-1}$

Note: The PFD metric and PFH metric are equal when the demand rate is once/year. Also, these failure-rate requirements are for an entire safety function and only a fraction of the above—for example, 1%—will be available to an individual IC.



1. Shown is a reliability bathtub curve.[1]

How to Start Predicting Your System's Reliability

Several databases exist to provide failure rates that system integrators can use when designing a system. Among the available sources of failure-rate data for electronic and non-electronic components are the IEC Technical Report 62380: 2004, Siemens Standard SN 29500, the ADI component mean-time-to-fail (MTTF) data, field returns, and expert judgment.[4]

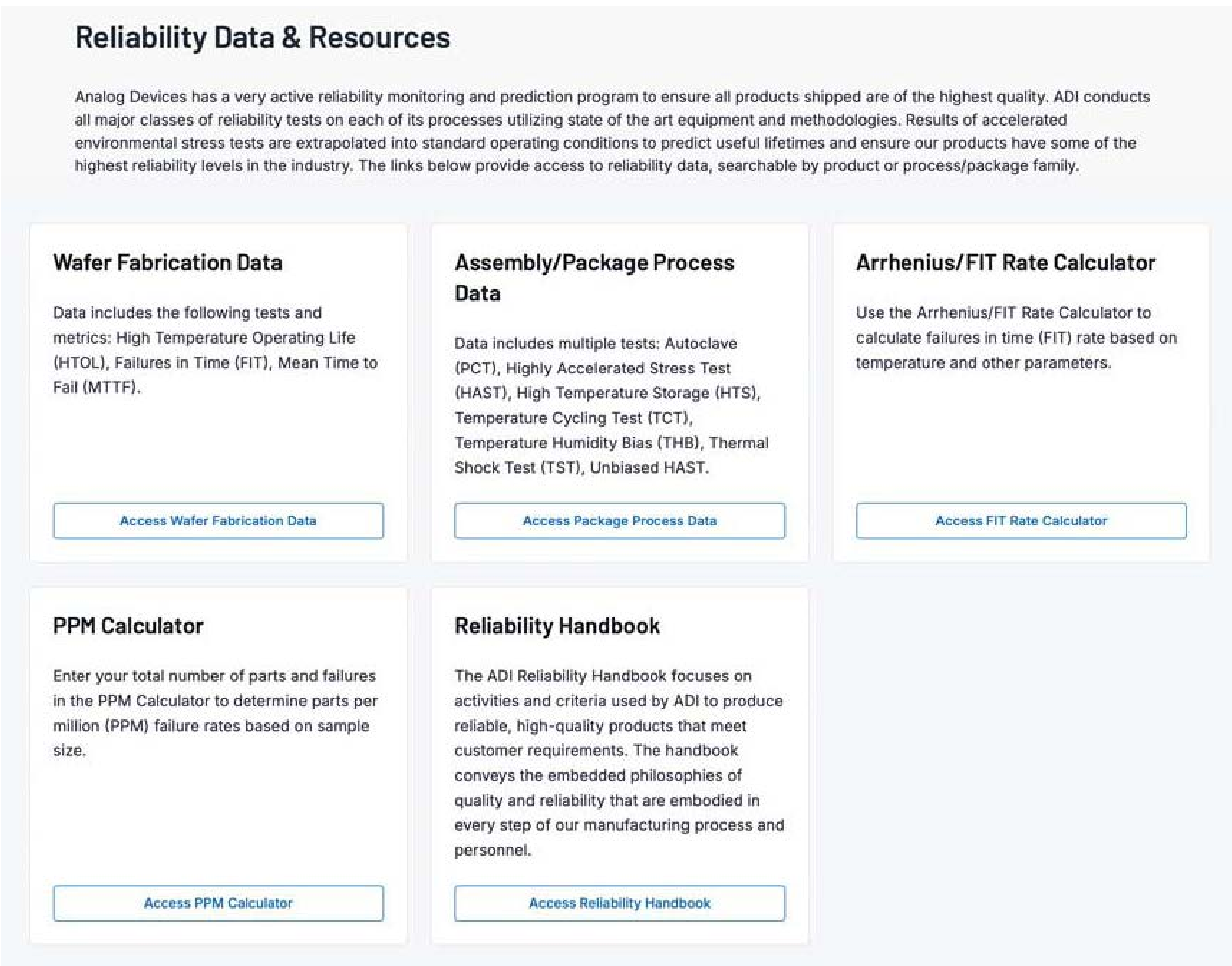
The ADI component MTTF data can be found at analog.com under the Reliability section. Under Reliability Data and Resources are the wafer fabrication data, assembly/package process data, Arrhenius/FIT rate calculator, parts per million calculator, and the reliability handbook. *Figure 2* shows what each resource subsection contains.

To help understand the differences between the first three cited failure-rate data sources for semiconductors—ADI component MTTF data focusing on Arrhenius high temperature operating life (HTOL), the Siemens Standard SN 29500, and the IEC TR 62380:2004—the following sections will provide some insights on each of those methods and the associated databases.[5,6]

What is Arrhenius HTOL?

HTOL is one of the most used accelerated life tests as defined in JEDEC standards to estimate component failure rate. HTOL testing aims to simulate device operation at elevated temperatures to provide sufficient acceleration to simulate many years of operation at ambient temperatures, typically at 55°C. Thus, HTOL estimates the long-term reliability of a semiconductor component—for example, MTTF—under accelerated stress conditions that compress the time to simulate the component's lifespan while heating it and maintaining its operational voltages.

Zooming into the details of reliability calculations, the data generated at the accelerated testing conditions of HTOL (1,000 hours at 125°C or equivalent) is translated to lifetimes at the end-user operating conditions (10 years at 55°C) by using the Arrhenius equation with an activation energy of



2. Analog Devices' reliability data and resources.

0.7 eV. The chi-squared statistical distribution is used to calculate the confidence intervals (60% and 90%) on the failure-rate data based on the number of units HTOL tested.

$$Failure\ Rate\ (\lambda) = \frac{x^2}{2 \times N \times H \times At} \times 10^9, FIT \qquad (1)$$

where:

- x^2 is the inverse chi-squared distribution whose value depends on the number of failures and confidence interval
- N is the number of units HTOL tested
- H is the duration of HTOL testing
- At is the acceleration factor from test-to-use conditions calculated according to the Arrhenius equation

Wafer fabrication data is one of the reliability data and resources available at analog.com. Clicking it will give data that includes a product's overall life-test data summary. This is composed of the overall sample size, quantity failing, the equivalent device hours at 55°C, the FIT values (based on HTOL data), and the MTTF data at 60% and 90% confidence levels. An example of this is shown in *Figure 3*.

Functional safety often requires a confidence level of 70%, so the 90% level can be conservatively used. Or it could be converted using a process such as that shown in "How to Change the Confidence Level of Your Reliability Predictions."[5]

What is Siemens Norm 29500?

The SN 29500 standard is a lookup-table-based standard that was initiated by Siemens and is widely used as the basis for the reliability predictions in ISO 13849. With this, the reliability prediction is calculated through failure rates, where the failure rate is defined as the proportion of failures that can be expected on average under given environment and functional operation conditions in a time interval. This

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ADI Overall Life-Test Data Summary	
Overall Sample Size	445576
Qty. Fail	0
Equivalent Device Hrs. @ 55 deg C	72503111445
FIT Rate (60% CL, 55 deg C)	0.01
MTTF (60% CL, 55 deg C) in Hrs in Hrs	079126817323
FIT Rate (90% CL, 55 deg C)	0.03
MTTF (90% CL, 55 deg C) in Hrs	31487770868
Calculations assumes 0.7 eV Activation Energy	

Please note: Where a device of interest is not sampled, it is valid to use the reliability data of the particular process technology to which the part belongs, since all parts within the same family are designed to the same rules and manufacturing as controlled by SPC.

The data provided in this calculation is generic data that reflects the overall reliability of the Wafer Fabrication Technology grouping for the selected product. The data may have been collected on the product selected or other Analog Devices products manufactured using the same technology grouping.

The data is intended to provide a high-level assessment of the reliability of the fabrication process used to manufacture a given product or products. Analog Devices products should never be operated outside the specified datasheet limits and this data should never be used as an indication of the Reliability of a product outside of those specified data sheet limits.

3. Wafer fabrication data tab from analog.com.

The FIT of the LTC2933 based on accelerated testing conditions of HTOL is detailed below:

Table 2-3 Functional Safety Component FIT According to HTOL Testing

Confidence Level	FIT (Failures Per 10^9 Hours)
70%	0.12
90%	0.23
95%	0.30
99%	0.46

Note 3: The FIT for various confidence levels were determined through HTOL reliability studies, utilizing the Arrhenius equation for acceleration assuming a chi-square distribution using the following test parameters:

- Sample size: 56686
- Number of Failures: 0
- Activation Energy: 0.7eV
- Accelerated Temperature: 55degC
- Equivalent Accelerated Device Hours: 10,078,622,220

4. FIT based on the Arrhenius HTOL according to the LTC2933 safety application note.

standard is recognized as representing a conservative approach to determine the component failure rates.

The reference FIT values per device category have basically been determined from field returns of the specific component class. For this reason, they would include any kind of failure type seen in the application and not only intrinsic failures as induced by the HTOL method shown in the previous section. This includes failures due to electrical overstress (EOS), which will not occur in the controlled lab environment used in HTOL testing.[5-8]

Equation 2 shows how the SN 29500-2 derives its failure rate for integrated circuits. First, it provides a reference failure rate that corresponds to the component failure rate under the standard-defined reference conditions. Since the reference condition will not always be the same, the standard also provides conversion models to calculate failure rates depending on stress operating conditions such as voltage, temperature, and drift sensitivity as shown in Equation 2.

$$\textit{Failure Rate } (\lambda) = \lambda_{ref}\pi_U\pi_T\pi_D,\ FIT \qquad (2)$$

where:

- $\boldsymbol{\lambda_{ref}}$ is the failure rate under reference conditions, which scales with the number of transistors
- $\boldsymbol{\pi_U}$ is the voltage dependence factor
- $\boldsymbol{\pi_T}$ is the temperature dependence factor
- $\boldsymbol{\pi_D}$ is the drift sensitivity factor

Depending on the nature of the IC, Equation 2 can vary. For example, when it's an analog IC with an extended range of operating voltage, Equation 2 can be used. For all other analog ICs with fixed operating voltage, the voltage dependence factor will be set to 1. For digital CMOS-B families, the drift sensitivity factor will be set to 1. Lastly, both voltage dependence and drift sensitivity factors will be set to 1 for all other ICs.

Note that the IEC 61709[9] standard provides information on how to translate a reliability prediction from one set of

The FIT of the LTC2933 based on SN 29500 for a specific industrial mission profile is detailed below:

Table 2-1 Functional Safety Component FIT According to SN 29500

SN 29500 Industrial Mission Profile	FIT (Failures Per 10^9 Hours)
Predicted Component FIT	85.28

- Mission Profile: 20 years constant operation at 55°C temperature
- Operating Voltage (max): 13.9V (based on product datasheet)
- Power Dissipation: 20mW
- Theta-JA: 110 °C/W

Note 1: For applications requiring a different mission profile, the following information can be used to calculate the base FIT based on SN 29500.

- SN 29500 part: Part 2 Table 5 under ASICs
- Sub-category: CMOS, BiCMOS
- Integration Density: 5k-50k
- Part is sensitive to drift

5. FIT based on the SN 29500 according to the LTC2933 safety application note.

conditions to another and appears to be the theory behind the SN 29500.

What is IEC Technical Report 62380: 2004?

IEC 62380 is another commonly used standard for estimating the failure rate of an IC. It was published in 2004 and subsequently replaced by the IEC 61709. Despite this, the IEC 62380 standard is still used as a reference in the automotive functional-safety standard ISO 26262:2018; it's still available in the 11th part as a model for reliability prediction of electronic components. This standard calculates the failure rate of an IC as a sum of the die, package, and EOS. The expression of FIT calculation according to IEC TR 62380 and ISO 26262-11:2018 is shown in Equation 3.[10-12]

$$\text{Failure Rate } (\lambda) = \lambda_{die} + \lambda_{package} + \lambda_{overstress}, FIT \qquad (3)$$

where:

- λ_{die} is the die failure rate that contains parameters related to the number of transistors, IC's family and technology used, and mission profile data such as temperature, working time, and influence factor of annual cycles
- $\lambda_{package}$ is the package failure rate that contains parameters related to the thermal factor, thermal expansion, mission profile's temperature factor of cycle, and IC's packaging
- $\lambda_{overstress}$ is the overstress failure rate that has corresponding terms for different external interfaces

Failure Rates in ADI's Safety Application Notes

Aside from the reliability data that can be found at analog.com, the reliability prediction of components for Analog Devices (ADI) can also be found in an IC's safety application note, which is typically available when an IC is tagged as FS-enabled. For instance, the LTC2933's safety application note shows the part's FIT values derived from HTOL, SN 29500, and IEC 62380 reliability prediction methods. This can be seen in *Figures 4, 5, and 6.*

The tables shown in the figures display the FIT values alongside the conditions considered. System integrators can use available information under the tables to calculate the FIT by themselves if they have different conditions.

Conclusion

This article provides an overview of the three most common reliability prediction techniques for integrated circuits, namely the Arrhenius HTOL, SN 29500, and IEC 62380. A calculation based on the Arrhenius formula utilizing the data from HTOL testing provides the failure rate in FIT. SN 29500 offers a reference failure rate as well as conversion models to consider different stress operating conditions. IEC 62380 provides the failure rate of electronic components as the sum of the die failure rate, package failure rate, and overstress failure rates.

For ADI, failure rates of components can either be found at analog.com or in a component's safety application note. The advantage of the safety application note is that it provides a component's reliability predictions based on the three methods discussed. On top of this, the information needed to calculate such FIT values is made available so that system integrators can redo the calculations for themselves if they have different operating conditions.

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The FIT of the LTC2933 based on IEC 62380 for a specific industrial mission profile is detailed below:

Table 2-2 Functional Safety Component FIT According to IEC 62380

IEC 62380 Industrial Mission Profile	FIT (Failures Per 10^9 Hours)
Total Component FIT	37.69
Die FIT	37.11
Package FIT	0.58

Note 2: For applications requiring a different mission profile, the following information can be used to calculate the base FIT based on IEC 62380.

- FIT calculation model: Section 7.3.1, refer to Mathematical Model
- IEC 62380 part and section for die FIT: Table 16, MOS ASIC circuits, Full Custom
- Production year for die FIT: 2017
- Integration Density: 5k-50k
- Climate type: World-wide (Table 8)
- IEC 62380 part and section for package FIT: Table 17b, Two Rows Connection Packages
- Package type: SSOP 16 pins, length: 4.89mm, width: 3.89mm, pitch: 0.64mm
- Technology Structure: MOS BiCMOS (Low Voltage)
- Substrate Material: Epoxy Glass (FR4, G-10)
- EOS FIT rate assumed: 0 FIT

6. FIT based on the IEC 62380 according to the LTC2933 safety application note.

SC65A and IEEE Functional Safety Standards Committee. Bryan has a postgraduate diploma in power electronics and around seven years of extensive experience in designing efficient and robust power electronics systems.

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