Reliability estimation for electronic designs

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Abstract

In this world of technology, on introduction of everynew featureand concept, the reliability of the system has always found to be the key factor foractually gettingaccepted by the masses for it. Hence, here is one such standard called the MTBF or Mean Time Between Failures which has been one of the most important factors in quantifying this reliability.

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Introduction:

Reliability is a probability that a product will operate satisfactorily for a required amount of time under stated conditions.Reliability is commonly quantified in terms of MTBF.

Mean Time Between Failures (or MTBF) is aarithmetic mean value ofsession time between two failureswhere the system is functional.

The following illustration explains MTBF graphically:

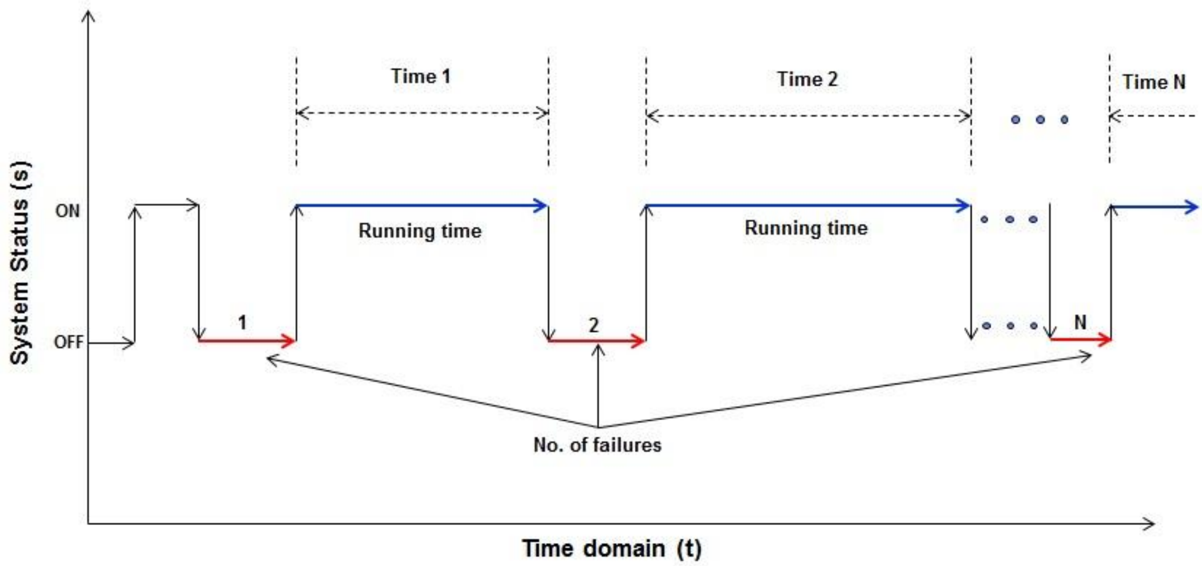

Figure 1 : Understanding MTBF

Here,

The time when the system is functional is mentioned as "Running time" and denoted as "Time 1, Time 2. . . Time N", while the number of failures is denoted as "1, 2 . . N".

Hence, MTBF can be expressed as:

MTBF = [Time 1 + Time 2 + . . . Time N] / [N]

MTBF is expressed in terms of hours. For example,MTBF of a hard disk can bearound 10,00,000hrs.MTBF of a Li-ion batterycan be around 1,00,000hrs while,Xilinxquotes that its 0.13µm process FPGA has a MTBF of a 20,00,00,000 hrs.

Rooting out the misconceptions:

- MTBF doesn't indicate minimum, guaranteed time to failure!
  - MTBF gives the MEAN value BETWEEN the failures and must not be taken as guaranteed time before first failure or between failures. Time to first failure (or between failures) can be calculated using the failure probability theory.
- MTBF value doesn't indicate useful life time of a system!
  - A battery cell having a useful life time of 5hrs may have a MTBF of 1,00,000hrs.
- On the timeline, if a group of systemshave totallycompleted 1000hrs of operation which is equaltheir MTBF value (i.e., MTBF = 1000hrs), then it is not a 50% probability for asystem beingfailed!
  - Due to exponential distribution of failure rate over time (see the equation of reliability below), 37% of systems may never fail even on reaching MTBF on the timeline while 67% of units mighthave failed once or more than once before the MTBF is reached.

Knowing the relatives of MTBF and how are they related?

Failure rate (λ): Rate at which components failper unit time. General notation for failure rate is 'X failures per million hours' but the common unit used in semiconductor industry is **FIT** (Failures In Time). FIT gives the number of failures in one billion hours of operation. Hence, FIT = 10^9 / MTBF.

Reliability (R): As already discussed, we know that that reliability is a probability that a product will operate satisfactorily for a required amount of time under stated conditions.

The following equation shows how all the three are related.

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

What are the standardsand softwaresfor calculating MTBF?

Commonspecs for the reliability of electronic components are **IEEE 1332** and **IEC TR 62380**. Many other standards are also followed.Application specificstandards are also available likeMIL-HDBK-217 (generally associated with military systems), Bellcore(Telcordia) for telecommunicationsIndustry standard, AIAG (for auto industry standard) etc.

Common softwares for simulating the reliability are ARINC Raptor, RelexOpSim, ReliasoftBlockSim etc.

When and How to calculate MTBF?

For pre-design MTBF calculations:

Method 1:

The MTBF can be calculated based upon the standards (say IEC 62380) where:

1. The standard definesa mathematical model (a formula) for every electronic component (for a transistor, a inductor, a diode etc.) to calculatetheir failure rate.

   This model covers the factors like quality of component manufacturing, environmental conditions, operational temperatures and the 'mission profile' which is a table giving the details on the ambient temperature cycles during life time of device, ON/OFF state durations, No. of operation cycles etc.

   Following is an example for mathematical model of a transistor as per IEC 62380.

MATHEMATICAL MODEL

$$\lambda = \left(\underbrace{\{\pi_S \times \lambda_0\} \times \left\{ \frac{\sum_{i=1}^{y} (\pi_t)_i \times \tau_i}{\tau_{on} + \tau_{off}} \right\}}_{\lambda_{die}} + \left\{ \underbrace{2.75 \times 10^{-3} \times \left(\sum_{i=1}^{z} (\pi_n)_i \times (\Delta T_i)^{0.68} \right) \times \lambda_B}_{\lambda_{package}} \right\} + \left\{ \underbrace{\pi_I \times \lambda_{EOS}}_{\lambda_{overstress}} \right\} \right) \times 10^{-9} / h$$

NECESSARY INFORMATION:

- $(t_{ae})_i$: average outside ambient temperature surrounding the equipment, during the i^{th} phase of the mission profile.
- $(t_{ac})_i$: average ambient temperature of the printed circuit board (PCB) near the components, where the temperature gradient is cancelled.
- π_S : charge factor.
- λ_0 : base failure rate of the die. See table on this page.
- $(\pi_t)_i$: i^{th} temperature factor related to the i^{th} junction temperature of the transistor mission profile.
- τ_i : i^{ame} working time ratio of the transistor for the i^{th} junction temperature of the mission profile.
- τ_{on} : total working time ratio of the transistor. With: $\tau_{on} = \sum_{i=1}^{y} \tau_i$
- τ_{off} : time ratio for the transistor being in storage (or dormant) mode.
- $(\pi_n)_i$: i^{th} influence factor related to the annual cycles number of thermal variations seen by the package, with the amplitude ΔT_i.
- ΔT_i : i^{th} thermal amplitude variation of the mission profile.
- λ_B : base failure rate of the transistor package. See Table 18.
- π_I : influence factor related to the use of the transistor (protection interface or not).
- λ_{EOS} : failure rate related to the electrical overstress in the considered application..

2. The effective failure rate is calculated as the sum of all individual component failure rates.

$$\lambda = \sum_{j=1}^{n} (\lambda_i)$$

Where, $\lambda_i$is thefailure rate of individual components and 'n' denotes the number of components.

3. The reliability is then calculated as per the reliability formula as a function of time and a graphof Reliability v/s time is plotted which would give the probability of survival.

Method 2:

This is less accurate but an alternate way of calculating the MTBF.

- If MTBF is already given, thenlambda can be calculated asLambda = 1 / MTBF.

  Else, for that component, we will need to consider a model which consists of factors multiplied together as shown below:

$$\lambda_{SS} = \lambda_G * \pi_Q * \pi_S * \pi_T * \pi_E$$

Here,

λ_{SS} = Steady State Failure rate, which is the effective failure rate of the component due to multiple factors influencing failures as shown in the equation.

λ_G = Generic or Base Failure Rate, which gives the basic valueof that component at well-defined operating conditions. These values will be usually from the field data.

π_Q= Quality Factor, which is determined by the level of quality at which the manufacturing process of that component is accomplished.

π_S = Stress Factor, which is determined by behavior of the component when it is subjected to abnormally high supply voltage. Note that the operating temperature increases with the increase in supply voltage.

π_T = Temperature factor,which is determined by the physical and chemicalprocesses of a semiconductor that strongly depend on the temperature.

π_E = Environmental factor like humidity, vibration, noise, dust, pressure, shock etc.to which the component is subjected during its operation.

- Lambda ofPWA =Lambda of component 1+Lambda of component 2+. . . + Lambda of component N.
- MTBF of PWA = 1 / Lambda of PWA.

Below example will help us to understand the MTBF calculation procedureas per method 2:

Given a assembled PCB (PWA), say there aresub-components like a RS232 transceiver (MAX3318EIPWR), a 4 bit voltage translator (SN74AVCH4T245PWR), a 3.3V switching regulator (TPS62040DGQ), a diode (B320-13-F), two PNP transistors (BSR16), ten resistor (All manufactured by KOA) and somefifteen capacitors (All manufactured by Taiyo Yuden).

For the sake of simplicity, the below example considers that MTBF is available for all components at the required quality, stress, temperature and environmental conditions to calculate lambda. If MTBF is not available or if the conditions are different, we will need to use the 'steady state failure rate'formula to calculate their actual failure rate.

The MTBF of the PWA can be calculated as:

Component	**Qty on board**	**MTBFin hrs** **(from the manufacturer)**	**Failure rate (λ) (in FIT)** **(= 10^9/MTBF)**	**Effective λ** **(= Qty * λ)**
RS232 transceiver	1	2290000000	0.437	0.437
4 bit voltage trans.	1	966100000	1.035	1.035

3.3V regulator	1	1340000000	0.746	0.746
Diode	1	98039215	10.2	10.2
Transistors	2	370370370	2.7	5.4
Resistors	10	270270270	3.7	37
Capacitors	15	2683123155	0.3727	5.591
Effective PWA failure rate(= sum of Effective λ)				**60.409**
PWAMTBF in hrs(= 10^9hrs/ Effective PWA failure rate)				**16553824.76**

Few key points that can be considered during the design stage to increase the MTBF:

Design planning and part count: It is always advisable to use the simplestpossible designusing least number components because lower part countscause lesser failures and thus yieldinghigher MTBF.

Picking up the components: Components which are picked need to have the required margins. For Eg: Given to choose a voltage regulator, if it is required to deliver a output current of 3A during its normal operations, then we need to make sure that the rated maximum output current of the regulator chosen is pretty higher than 3A (around 5A). The reason is that the maximum current ratings of a regulator is quoted at certain test conditions and hence the regulatormight be actually capable of givingonly 4A with easewithout getting itself subjected to any electrical stress. Additional consideration also needs to be done like handling the initialcurrent drawn by every ICfrom the regulator output etc.

Just like the example ofthe regulator, care needs to be taken for every component, likefor capacitors it would be w.r.t their rated voltages, for resistorsit would be w.r.t their power ratings etc. These precautions will keep the design less prone to failures.

MTBF across same type of components: For Eg:Two manufacturers producing same type of component may have different MTBF values. Using theone having higher MTBF would be ideal as it indicates to be more reliable.

Thermal considerations: Design need to planned such that thermal consideration are done like using heat sinks, fans, heat spreaders, proper clearance for air flow across the components surfacesetc.Thermal analysis using various tools allows identifying the components that may create hotspots.

Redundancy: After considering the trade-off between 'Warranty cost v/s design implementationcosts',if possible, providing alternative flow in designwill increase the MTBF greatly because, failure of a component may not be affected as the alternate component takes care of the task. Still, this method is less preferred becauseeven though thisincreases system MTBF,it decreases hardware MTBF due to increase in number of components.

Pros:

- Helps to find the weak links during the design stage and aids to improve the design to attain higher MTBF resulting in higher reliability.
- Can get anapproximate MTBF value for new designs for marketing purposes.

For post-design MTBF calculations:

1. Keeping track of all the systems delivered as well as at the lab andcollecting the run time of all these systems.
2. Tracking the number of failures during theirrun, either reported by the customer for the delivered ones or observed in the ones at the lab.
3. Calculating the MTBF as:

MTBF = [Total No. of systems * Total run time of thesystems] / [No. of failures]

Pros:

- Will get the actual "field MTBF" as the system is considered as a whole, all the inter-relation of components in the design are pulled out as well assoftware (and mechanical factors also if applicable) are considered.
- Helps to find actual weak links in the design in the later stage as the designer would get the failure report and the analysis of these reports

help to find the common weak link and rectify in the next revision of the system.

Cons:

- Not a one time job and is a continuous process.

Last note:

Even though MTBF gives a good picture of the system stability, it must not be the only statistical measurement for quantifying the system reliability. MTTR (Mean Time To Repair), MTTF (Mean Time To Failure) etc. would be other factors which influence the reliability too. Hence it has been always advisable to consider the overall factor rather than solely deciding on any particular standard of representation.

Keywords:

MTBF, Reliability, failure rate, IEC standard,stability, hours, components, quantify calculation, lambda, system and factor.

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