Traditional EEE Part Testing versus "Higher Assembly" Validation Tests

Is Better the Enemy of Good Enough?

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“Good Enough?”

- The **reliability** of a system is the probability that it will **work-to-spec** throughout the **design life**.

- Our goal is that our systems are **reliable enough** for our **needs**.

- **Needs** vary with the **work** expected of the system.

- A system that is “good enough” for one set of needs, may not be “good enough” for a different set. “Is it ‘Good Enough’?” does not have a universal answer.

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‘Two days wrong!’ sighed the Hatter. ‘I told you butter wouldn’t suit the works! he added looking angrily at the March Hare.

‘It was the **BEST** butter,’ the March Hare meekly replied.

Two Hard Problems:

1. How does one determine the **probability** that the system will work per spec for a given time?

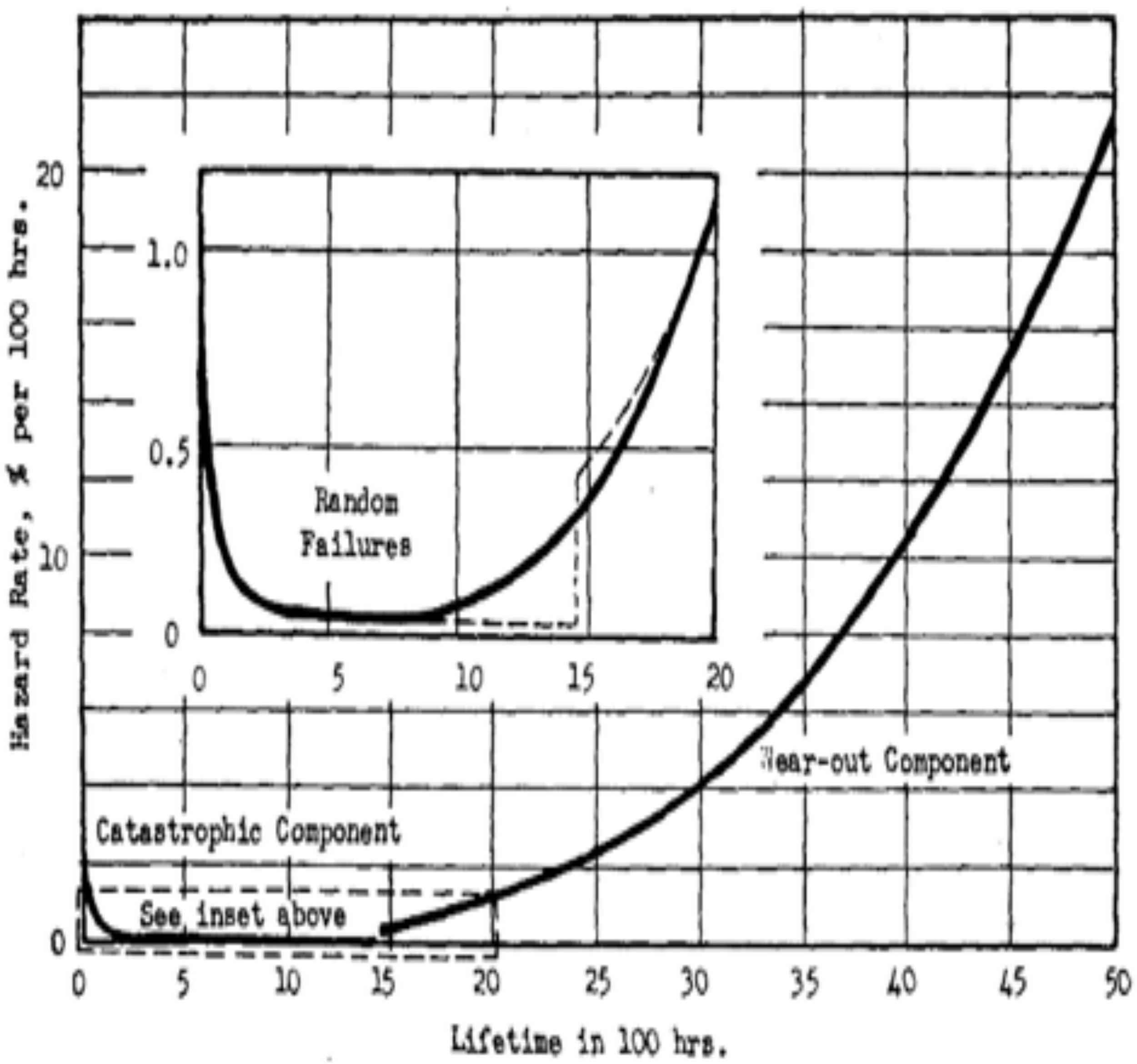
2. How does one judge the **need to work per spec**, and especially, what are the consequences of **failure**?

Knowing the Probability

1. One way to know the probability of an event, ***P(E)***, is to have a sample of ***N*** systems, all clones of each other, and a count of the number ***n*** in which the event happens. Then ***P(E) ~ n/N***, with the quality of the approximation improving with increasing ***N***. Some users (auto makers) often have sizes on ***N*** into the millions, and can use this method nicely. But sometimes, for us, ***N = 1*** : this fails.

2. Another way is to analyze the system into components down to the level at which one has a large population of replicas of these components, so that Method 1 can be used to estimate probabilities of the various behaviors of the components, ***p*** ; then, one synthesizes the system from these, and assembles ***P*** from the component values of ***p***. This can be done well, or alternately, as MIL-HDBK-217 does it (sigh).

The olden days --- vacuum tubes



- The hazard (failure rate) of vacuum tubes shows "**infant mortality**" --- it is large at first, and then drops.
- The hazard also shows "**wear out**" --- it is small at first, and then explodes with aging.
- And they just do not live very long --- a few thousand hours is typical.

1970 to 1995

- Transistors and Integrated circuits are “rocks”: when assembled correctly, they have lifetimes that can be centuries and more.
- Many (not all) circuit elements in the Shuttle systems are ~ 1975. Retests showed no evidence of aging (in many cases), except in cases of mis-built parts.
- But accidents-of-assembly happen --- thus, we pay serious attention to the dates on which the components were assembled, so that we can hope to expunge other like-parts when one fails.
- GIDEP —> part-specific & production-lot-date-specific.

Post-1995

- From roughly 1960 to 1980, the market for MIL-style parts and hi-rel parts was as large as 50% of the total, both in volume and in money.
- Today, the same “absolute” demand for MIL-style and hi-rel parts exists. But the commercial market has grown by about a factor of several hundred times.
- Hence, “we” are now ~ 0.1% to 0.3% of the market.
- Manufacturers have been dropping “our” lines!

Components designed to have hi-performance by sacrificing lifetime!

- Silicon real-estate is expensive and parts are being sold that crowd increasing numbers of elements onto the silicon.
- This increases failure rates since
  - dielectric layers are thinner and therefore easier to puncture.
  - aluminum traces are thinner and therefore easier to open by electro-migration.
  - smaller feature size increases the chance of “hot electron” effects.
- No “ESD” protection!
- No history on the parts --- active production of months.

Bad Parts - Swift/BAT

- Swift had a two year planned mission life, and is now celebrating its 10th year of operation with "all systems go". Its gamma ray detector, the Burst Alert Telescope (BAT), has detected more than 800 Gamma Ray Bursters!

- The BAT is a 16,384 channel gamma ray detector, made using a combination of "hi-rel" parts and "COTS" parts. **It uses about 100,000 COTS parts, distributed over 52 distinct part-types** — using "hi-rel" parts only would have incurred an "astronomical" cost. Screening showed that three of the part-types (**6%**) would have been lethal.

- The designer was delighted with the specs of the OP296, a BiCMOS op amp — it was especially fast, and especially small, and especially modest in its power requirments. The test pieces worked admirably, and so it was designed into each of the 16,384 channels. The first "lot" was purchased and installed: these did not work as well as the test pieces. The second "lot" was worse. The third "lot" was still worse. While pondering what to do about this, the designer chose (at last) to carry out checks for any impacts of total ionizing dose — the part showed profound parametric shifting at less than 1.0 kRAD, and complete functional failure at about 1.8 kRAD. The mission life of BAT would have been at most a few months! Replacing this part was painful: daughter boards had to be introduced, as well as new power supplies. **MORAL: do not skip radiation testing!**

- A second lethal part was used in power supplies. It was not robust (enough) under soldering temperatures, and developed internal shorting paths that could spontaneously deliver lethal voltages to downstream components. Use of this part could wipe out many other parts.

Bad Parts that Escaped Screening - Magnetospheric Multiscale (MMS) Mission

- MMS is a system of four satellites positioned in a tetrahedron to acquire field-data over a 3D zone of space. All four satellites should work: this is an **anti-redundant** system.

- MMS uses 306 high voltage switches: the HV-801. After screening and installation into the satellites, five became too leaky for their circuits to function. Study has found many distinct leakage paths develop as the device is operated: we have not found a reliable way to screen these to eliminate these **delayed failures**.

- MMS uses hundreds of devices using laser-marked lids: one of these devices failed after working correctly for (about) 300 hours: **a delayed failure**. Inspection showed a hole in the lid, drilled completely thru the lid by an enthusiastic pulse-string from the laser marking tool. Delidding showed massive corrosion inside, and some chlorine products. A review of the assembly process showed the use of Tri-Chlor. This prompted a review of the production methods used by the manufacturer of this part: we learned that this problem could affect ALL parts marked by this tool, and not just the particular part-type that MMS found to fail, and not just that lot-date-code. This reminded us of a profound difficulty with the GIDEP system, which supposes that problems are limited to the part-type in which a failure is found, and the lot-date-code of that part's manufacture! We also learned that the screen used by the manufacturer to detect leaks has a non-zero escape rate!

- MMS uses many Micropac 53250 optocouplers. Some became thermostats during I&T: they would stop working when the box was elevated over a critical temperature, varying from about 35C to 50C, depending on the example, and then resume working when returned to room temperature. The gold pad was lifting from, and returning to, the LED. This was not captured during our original screens, but was a **delayed failure**. We found that a step-stress screen was effective at locating the few parts with this problem.

Bad PW-Boards

- The GSFC Project GLORY used a Maxwell "Single Board Supercomputer" — the pw-boards made by DDi had several varieties of flaws in it that caused "re-boots" during I&T testing over a range of temperatures. These were initially suspected to point to a problem with one (or more) parts. It took many weeks to locate the problem to a thermostatically-activated problem in the pw-board — actually, to a variety of thermostatically-activated board-flaws. Attempts are made to make satisfactory pw-boards: 11.6 million dollars were spent on the trouble-shooting that identified the problem, and then on attempts to make satisfactory pw-boards (the 96th run was successful!), and 49.3 million dollars were associated with maintaining the contractor during the 15-month launch delay.

- A "national asset" communications satellite managed by GSFC exploded a power distribution board during final thermal-vacuum testing. Strenuous investigation found that the cause was the "stroking" of each of five pw-boards past a broken drill bit protruding from the first pw-board, rejected because that broken drill bit was found to be not-removable. The knife-edge cut into the soft exposed laminate, which was then plated over: the ingested plating solution plus fiber damage allowed conductive filament growth that resulted in "metal vapor arcing" (about 800 A @ 50 V for almost one second) of one of the pw-boards; CT inspection then showed that the other pw-boards were on their way to having copper filaments bridging between ground and power planes.

- GLAST (renamed FERMI) had a dozen pw-boards (in a lot of 350) develop circuit-killing leakage paths when conductive copper filament bridged between traces — this was caused by a combination of more moisture than usual, and delaminations between glass fibers and laminate, and applied voltage (about 100 V).

- **MORAL: pw-boards are not always perfect**; rather, some have problems that can result in system failures. Note that the above examples show DELAYED failures, only manifesting late in the development cycle. The problem with the first example was apparent in the first coupons examined, and also in IST testing. The "national asset" pw-board problem could never have been expected to show in coupon testing, or IST testing. The third problem was noted by a pro-active testing by the pw-board populator, who checked trace-combinations for leakage. **GSFC testing has shown a persistent 15% to 20% coupon rejection rate.**

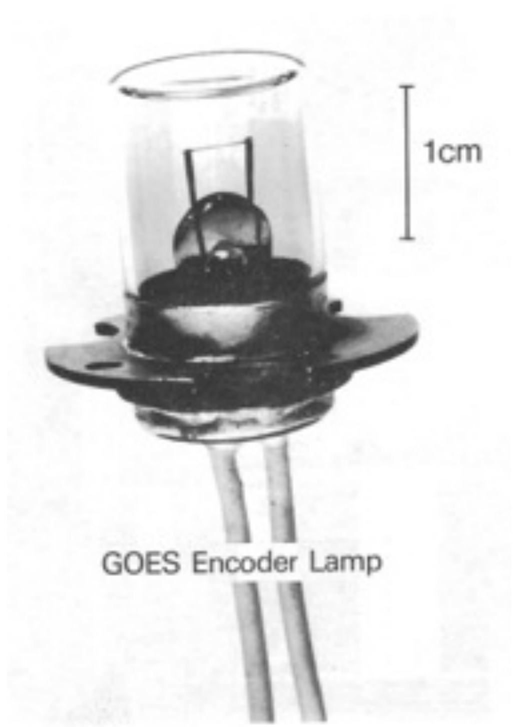
Lowering the Probability of Installing Bad Parts onto a PW-board

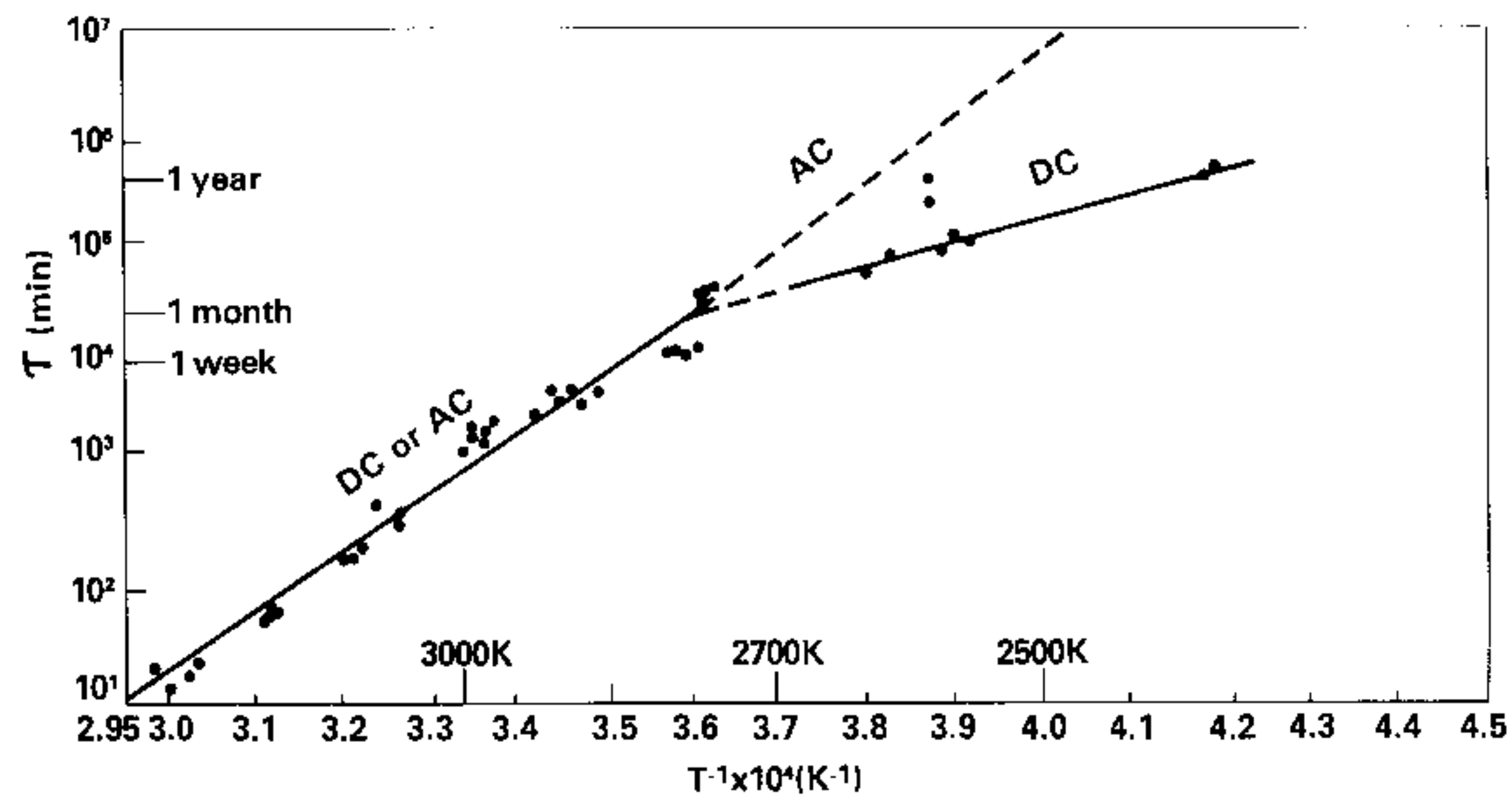
- Minimum Screening: Install only parts that show that they work correctly over the entire normal design-range of its environment (operating voltages, temperatures, accelerations, radiations).

- Agressive Screening: Install only parts that show that they work correctly over a wider range of conditions than the normal design-range. The wider ranges are chosen to make apparent any flaws that would become apparent at a later time under normal conditions. Choosing appropriate “wider ranges” calls for good engineering judgment — any part can be broken by a “big enough” hammer, and this will not be useful to us. Experience shows that correct operation at temperature extremes, and at voltage extremes, is useful in quickly evoking failures that would happen eventually during normal operation.

- Generally speaking, “agressive screening” cannot be carried out when parts are mounted onto pw-boards: the circuits cannot (usually) provide extremes of voltage, or allow the perception of anomalous behaviors of each part, unless many many test points are built-into the system. (Sometimes, not even then.) Therefore, failures that are both prompt and profoundly consequential, under modest conditions, can be detected. But delayed failures and failures that begin as subtle changes in performance are likely to be missed during board-level testing.

Accelerated Testing: Incandescent Lamps for GOES





Consequence of Failure

- Failure may be essentially harmless — such as a pen does not write, so you pick another from the pen-pile on your desk.

- Failure may be horrible — such as a thermonuclear weapon having an uncommanded detonation.

- Usually, the consequences are somewhere in between. But detailing these consequences can be difficult — it means we have to address failure.

Consequences of having a bad part or a bad board

- Bad parts or a bad pw-board (usually) have to be replaced in order for the system to operate per spec. Locating this problem is costly, sometimes very costly. (GLORY: 62 M$)

- A bad part, or a bad pw-board, can damage otherwise good parts on the pw-board — One may have to replace more than the bad part, or the bad pw-board, after one locates the mis-performing item.

- Restoring correct operation may not complete dealing with the mis-performance — users may now lack complete confidence in the performance. (Packard-Bell, Taurus)

- Failing to detect the bad part, or bad pw-board, during testing then “fields” a bad system — failure can be delayed until performance is needed. Will the pen write? Will the defibrillator resuscitate? Will the launch craft shroud separate? Will the thermonuclear bomb detonate as designed and not otherwise?