Non-Operating Reliability

18-849b Dependable Embedded Systems

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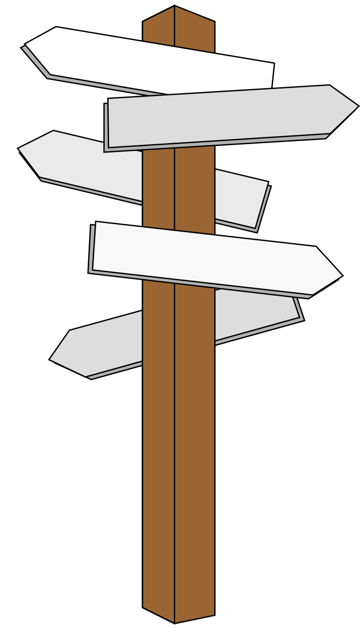
Required Reading: "Reliability Assessment of Electronic Components Exposed to Long-Term Non-Operating Conditions", McCluskey et. al., 1998.

Authoritative Books: "Long-Term Non-Operating Reliability of Electronic Products", Pecht 1995.

See references

Carnegie Mellon

Overview: Non-Operating Reliability

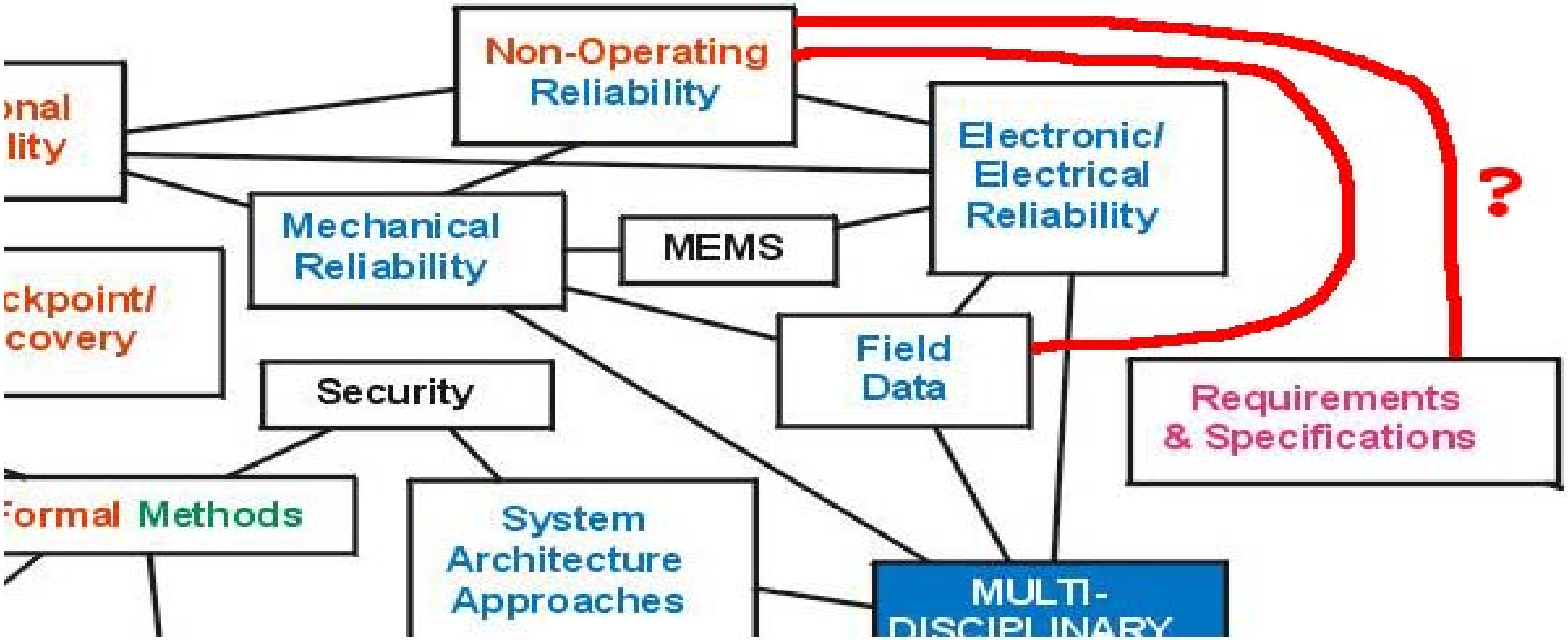


- **Introduction**
  - Definition
  - Clusters it belongs to
- **Key concepts**
  - The Non-Operating Environment.
  - Failure Mechanisms
  - Failure Rate Distribution
- **Tools / techniques / metrics**
  - Reliability Models
  - Dealing with Non-Operating Environments
- **Conclusions & future work**

Introduction/Definitions

- **The Non-Operating Condition/Dormant State**
- **Different definitions here and there**
  - Includes parts/systems:
    - Connected to a functioning system such that they are immediately ready to operate on demand.
    - Where there is a reduction or elimination of most of the physical, electrical stressed compared with operating condition.
  - Sometimes doesn't include
    - Equipment operating at low levels of its function, disconnected or in storage.
  - We're going to group both storage and dormancy environments together.

YOU ARE HERE MAP



- **Can be related to:**
  - Field Data
  - Requirements and Spec.
  - Maintenance
  - Environment/EMC/EMI
  - Many more really.. Traditional, Mechanical, Electrical Reliability

Non-Operating Environments

- **Some usage data:**

Typical Percentages of Calendar Time for Equipment in Dormancy [Harris, 1980]

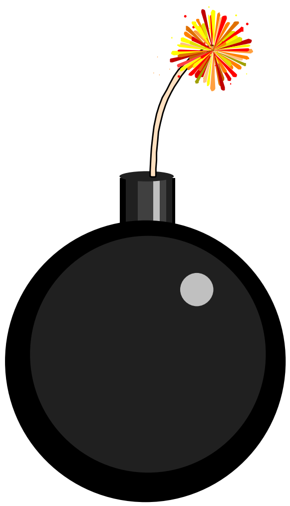
Cars (personal use)	93%
Taxis	38%
Safety equipment	98%
Standby power	> 90%
Air conditioning	50% - 80%
Built-in test equipment	99%

- **Diurnal temperature ranges from -50C - +75C**
- **Relative humidity, sea spray, industrial pollutants, mechanical shock, fungus, [Livesay, 1978], sand, dust, extreme temperatures [Pecht95]**

Failure Mechanisms

- [Pecht95] gives a very complete listing of mechanisms but not a lot of talk about which are most common in practice.
- Perhaps because "in practice" varies from environment to environment and from application to application.

- Electrical Failure Mechanisms
- Corrosion Failure Mechanisms
- Radiation Failure Mechanisms
- Mechanical Failure Mechanisms



Failure Mechanisms (cont.)

- **Electrical Failure Mechanisms**
  - ESD, Lightning
- **Mechanical Failure Mechanisms**
  - Temperature Cycling: portions of IC die have different thermals expansion coefficients: dies can fracture, chips can pop off board.
  - Failures induced by Shock/Vibration:
    - Flexing of leads and interconnects.
    - Damaging of pumps, bearings, and electronics.
    - Dislodging of foreign particles in filters.
  - Failures Induced by Sand/Dust:
    - Can degrade equipment by abrasion, causing friction (wear and heat)
    - Abrasion of optical surfaces
    - May provide corrosive effects if alkaline, acidic, or microbiological.

Failure Mechanisms (cont.)

- **Corrosion Failure Mechanisms (Dry & Wet)**
  - Temperature falls below dew point.
  - Moisture can enter through cracks.
  - Present in IC package from time of manufacturing.

  - Types: Galvanic Corrosion, Crevice Corrosion, Defects in Passivation, Pitting Corrosion, Surface Oxidation, Corrosion due to Microorganisms.
- **Radiation Failure Mechanisms**
  - Mechanical Degradation: Embrittlement, alter properties, etc.
  - Electrical Degradation:
    - Alpha particles can accumulate?
    - Gamma and Neutron Heating..

Failure Distribution

- **Exponential arrivals and Poisson distribution imply constant failure rates.**
- **Common to regard most:**
  - Electronic parts as possessing patterns of failure that follow exponential distributions.
  - Mechanical parts as following Normal or other failure rate showing increasing failure rates with time.
- **In the Non-Operating environment, there is <u>evidence</u> that most electrical/mechanical systems/parts have a constant failure rate.**
  - HOWEVER, Not true for all components and creates problems with certain reliability assessment models.
    - Electrolytic capcitors

Non-Operating Reliability Assessment

- **Specific Field Data**
- **RADC-TR-85-91 Method**
  - $\lambda_p = \lambda_{Nb} \Pi_{NT} \Pi_{NE} \Pi_{NQ} \Pi_{cyc}$ (base rate * non-operating factors)
- **MIL-HDBK-217 "Zero Electrical Stress Approach"**
- **The "K" Factor Approach**
  - Switches 10:1, ICs 80:1, Mechanical Parts 30:1 - 60:1
- **The Martin-Marietta Test Program**
- **Automated Reliability prediction programs**

Failure Rates [Harris, 1980]

Relays, 5 Amp.

Source	Dormant Failure Rate
Field Data	.032
K-Factor Approach (Ratio Method) 1:60	.046
MIL-HDBK-217 Model	.058

Connectors, PCB

Source	Dormant Failure Rate
Field Data	.0015
K-Factor Approach (Ratio Method) 1:60	.0007
MIL-HDBK-217 Model	.042

Dealing with Non-Operating Environments

- **Physics of Failure Based Approach**
  - Define Realistic System Requirements
  - Define the System Usage Environment
  - Identify Potential Failure Sites and Mechanisms (FMECA)
  - Characterize the Materials, Manufacturing and Assembly Processes
  - Design Reliable Products Within the Capabilities of the Materials and Manufacturing Processes Used.
  - Qualify the Manufacturing and Assembly Processes
  - Control the Manufacturing and Assembly Processes
  - Manage the Life Cycle of the Product

Conclusions & Future Work

- **Designing for operating reliability is not necessarily the same as worrying about non-operating reliability.**
- **No single most common failure mechanism. It all depends on YOUR particular environment.**
- **Moisture is one of the larger enemies.**
- **Often a bunch of failure mechanisms that cause problems, not just the existence of one.**
- **Statistically significant part failure data not always available to designer; Careful assessment of the potential dangers to device technologies is key.**
- **Models can be inaccurate.**

The Paper...

- **“Military/Aerospace industries are indeed being ‘forced’ to use PEMS, a package technology which has been shown to be just as reliable as older cavity type DIPS”**
- **Summarized previous work testing COTS PEMS**
  - PEMS perform good enough in most long term applications.
  - Components not the limiting factor; board assemblies are.
  - Intermittent use is a more severe corrosion environment that either long term storage or continuos use.
  - Automotive environment at least as harsh as field storage environment.

List of References...

- **[Livesay78]** Livesay, B.R. The reliability of devices in storage environments. *Solid State Technology*. (October): 63-8.
- **[Harris80]** Harris, A.P. Reliability in the dormant condition. *Microelectronics and Reliability*. Vol 20. p33-44. 1980.
- **[McCluskey98]** McCluskey, F.P., E.B. Hakim, J. Fink, A. Fowler, and M. Pecht. Reliability assessment of electronic components exposed to long-term non-operating conditions. *IEEE Transactions on Components, Packaging, and Manufacturing Technology*. Part A. Vol 21. No. 2. (June): 1998. 352-359.
- **[Electronics Reliability Subcommitee87]** Electronics Reliability Subcommittee. 1987. *Automotive electronics reliability handbook*. Warrendale, PA: Society of Automotive Engineers, Inc.
- **[Pecht95]** Pecht, J. and Pecht M. *Long-term non-operating reliability of electronic products*. Boca Raton, FL: CRC Press, 1995.