ELEC 3106
Study Notes

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Semester 1 2013 – Electrical Engineering
The University of New South Wales

NOTICE:

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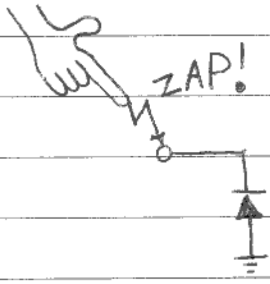
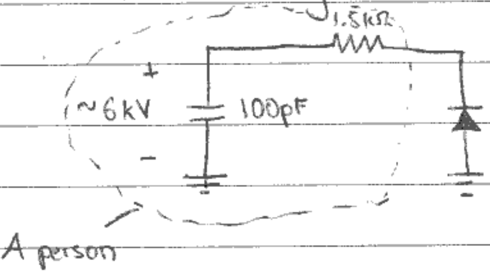
NOTES: Week 12 - Circuit Failure, FMEA & Reliability

Types of failure

- Electrostatic discharge



The diode is damaged due to excessive reverse breakdown. The body can be modelled as:



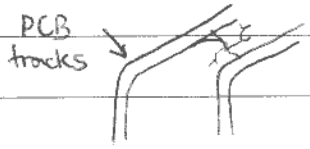
This could leave the device permanently SC or OC, or having leakage currents (over time) due to several smaller ESD events.

- Electromigration

  Particularly occurs in ICs. Conductive wires go OC over time due to electron flow actually causing the wire's atoms to shift.

- Dendritic growth / dielectric breakdown

  Moisture helps form thin electrolytic coatings called 'dendrites'



  between conductors, eventually shorting out. Dielectric breakdown could also occur, if a high E is observed. Can be permanent in MOSFETS or capacitors.

- Photolithographic defects

  Occurs in PCBs and ICs, due to dust particles present during manufacturing. Very bad because everything is OK at the initial operation, but may accelerate dendritic growth or electromigration, leading to early circuit failure.

- Junction spiking

  Impurities short out p-n junctions at elevated temperatures.

NOTES: Week 12 - Circuit Failure, FMEA & Reliability

- Parameter Shift

  Movement of the material causes a shift in component values like capacitance & resistance. Charge (data) stored on non-volatile memory might be lost.

- Stress & Thermal Cycling

  Mostly self-explanatory, if you did middle school physics you'd realise that hot and cold things expand and contract. Things like solder, and chip contacts, and the circuit board itself.

- Contact Wear

  Repeated use of interconnectors, jumpers, switches, anything mechanical, are often cited to be weak points in the system causing early failure. Often oxides will form on the conductors. We may alleviate this somewhat by using noble metals.

- IC Corrosion

  Ions can leak into the IC package, causing damage to it.

- Cosmic Radiation

  Causes generation of electron-hole pairs in a semiconductor junction, inducing current that might not permanently damage the device but is known to bit-flip stored digital memories.

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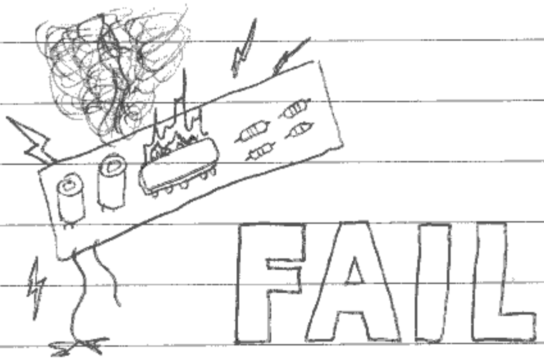
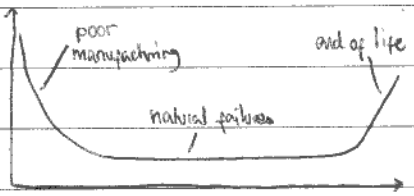


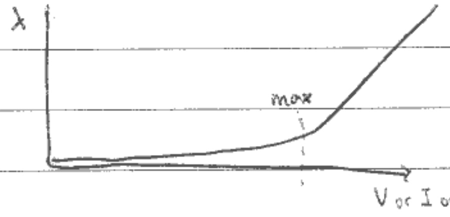
We depend on a number of formulae in dealing with failure statistics:

- Failure distribution function $F(t)$
- Realiability function $1 - F(t)$
- Failure probability density $f(t) = \frac{dF(t)}{dt}$
- Hazard function $\lambda(t) = f(t)/(1-F(t))$
- Failures-in-time $1 \text{ FIT} = 10^{-9} \text{ h}^{-1}$.
- Mean time between failures (MTBF) $1/\lambda(t)$

$\lambda(t)$ →



- Failure rate → often dependent on temperature → $\lambda_T = \Lambda_0 e^{-E_A/kT}$



- Failure acceleration or Mean time to Failure (MTTF)

$$MTTF = F^{-1}(1/2)$$

NOTES: Week 12 - Circuit Failure, FMEA & Reliability.

We expect consumer electronics to have an MTTF of 10 years, minimum. But it is important to verify that your MTTF is as low as possible so that customer confidence is upheld. Clearly a number of Microsoft quality assurance engineers failed to put the first-generation Xbox 360 through these tests. We estimate MTTF as follows.

1/ Define acceleration factor AF at a usage temperature and a test temperature:

$$AF = \frac{\lambda_{T_2}}{\lambda_{T_1}} = e^{E_A/kT_1 - E_A/kT_2}$$

2/ Using F(t) definition, we prove that:

$$F_{T_2}(t) = F_{T_1}(AF \cdot t)$$

3/ We finally find:

$$MTTF_{T_2} = \frac{MTTF_{T_1}}{AF}$$

Do NOT take acceleration factor too high though, you'll probably end up melting your circuits. We should use burn-in tests to weed out the stragglers, the runts - devices are stressed so the poorly manufactured ones will fail.

Failure distribution function

Complex components suffer from random failures, failure rate is constant ($\lambda(t) = \Lambda$)

$$\Lambda = \frac{dF_R(t)/dt}{1 - F_R(t)}$$

some mathematics later...

$$F_R(t) = \int_0^t \Lambda e^{-\Lambda t} = 1 - e^{-\Lambda t}$$

Another failure distribution is the Weibull distribution function:

- $\alpha > 0$: scaling parameter
- $\beta > 0$: shape parameter

It can simply model failure rates at every point in a component's lifespan:

$$F_W(t) = 1 - e^{-(t/\alpha)^{\beta}} \begin{cases} \beta < 1 & \text{infant mortality} \\ \beta = 1 & \text{constant failure} \\ \beta > 1 & \text{increasing failure.} \end{cases}$$

Devices, of course, are made with many components and it's pretty reasonable to assume if a major one dies, so does the entire circuit.

Therefore, the failure distribution of a device made up with N components:

$$F_{dev}(t) = 1 - \prod_{i=1}^{N} (1 - F_i(t))$$

$$\lambda_{dev}(t) = \sum_{i=1}^{N} \lambda_i(t)$$