Reliability First -
From the Bathtub Curve to Design for Stress

AEC Reliability Workshop - Novi

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From the Bathtub Curve to Desing or Stress

- Bathtub curve
- Life Screening
- Design for Stress

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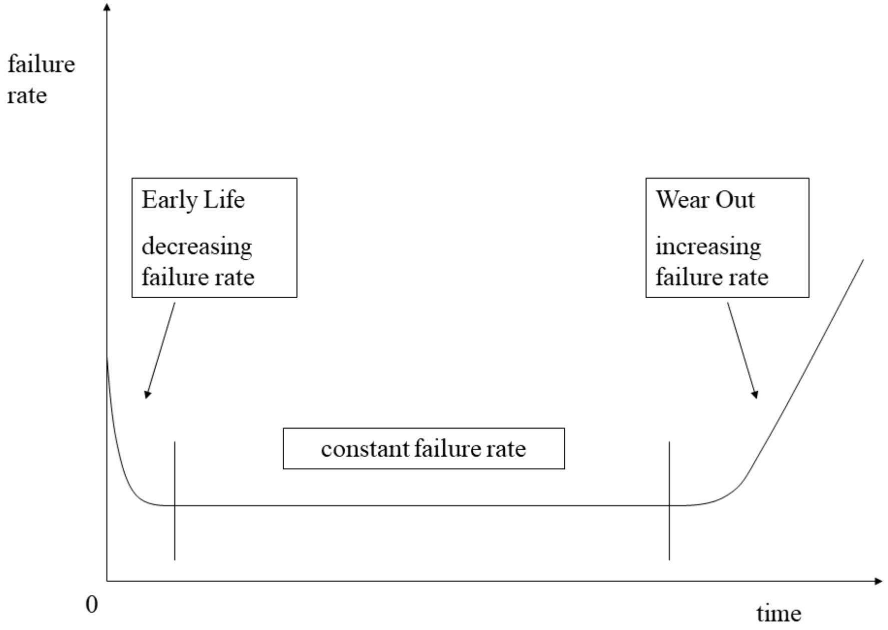
From the Bathtub Curve to Desing or Stress

- Bathtub curve



  - Well established model
  - Considered as good approximation
  - Dielectric materials:
    → derivation possible

From the Bathtub Curve to Desing or Stress

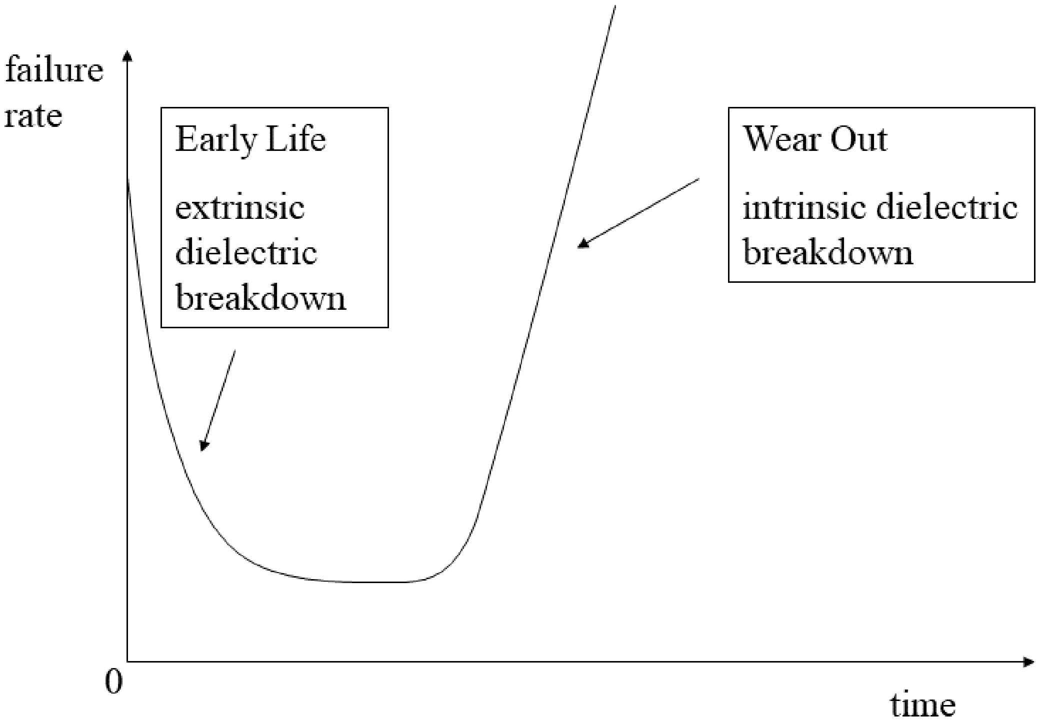
- Dielectric material – failure mechanisms

  - Extrinsic dielectric breakdown
    - Material with defects
    - Fails before end of life
    - Typical:
      - Weibull distribution with $\beta < 1$

  - Intrinsic dielectric breakdown
    - Material with no defects
    - Fails at end of life
    - Typical:
      - Weibull distribution with $\beta > 1$

From the Bathtub Curve to Desing or Stress

- Dielectric material – failure mechanisms



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Life Screening

- Screen Stress
  - High acceleration at dielectrics
    - Temperature *T*: Arrhenius law
    - Voltage *V*: linear E model

$$t_{use} = AF_T \cdot AF_V \cdot t_{stress}$$

$$AF_T = e^{\frac{E_a}{k} \cdot \left(\frac{1}{T_{use}} - \frac{1}{T_{stress}} \right)}$$

$$AF_V = e^{\frac{\gamma}{d_{oxide}} \cdot (V_{stress} - V_{use})}$$

with

- t_{use}, t_{stress} = usage and stress time,
- E_a = activation energy, typical 0.7 eV,
- γ = field acceleration factor.

Conditional Weibull Distribution

- Voltage stress screens out lifetime
  - survivors are delivered
    → conditional Weibull distribution

$$F(t|t_{stress}) = \frac{F(t_{stress}+t) - F(t_{stress})}{1 - F(t_{stress})}$$

$$= \frac{1 - e^{-[(t_{stress}+t)/\eta]^{\beta}} - 1 + e^{-[t_{stress}/\eta]^{\beta}}}{1 - 1 + e^{-[t_{stress}/\eta]^{\beta}}}$$

$$= 1 - \frac{e^{-\left[t_{stress}\cdot\left(1+\frac{t}{t_{stress}}\right)/\eta\right]^{\beta}}}{e^{-[t_{stress}/\eta]^{\beta}}}$$

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Conditional Weibull Distribution

- Taylor series expansion

$$(1+x)^{\beta} = 1+\beta\cdot x+\frac{\beta\cdot(\beta-1)}{2}\cdot x^{2}+\cdots$$

- For small *x*, skip higher order terms; → $t_{stress} \gg t$

$$F(t|t_{stress}) = 1-\frac{e^{-\left[t_{stress}\cdot\left(1+\frac{t}{t_{stress}}\right)/\eta\right]^{\beta}}}{e^{-[t_{stress}/\eta]^{\beta}}} = 1-\frac{e^{-[t_{stress}/\eta]^{\beta}\cdot\left(1+\frac{t}{t_{stress}}\right)^{\beta}}}{e^{-[t_{stress}/\eta]^{\beta}}}$$

$$F(t|t_{stress}) \approx 1-\frac{\cancel{e^{-[t_{stress}/\eta]^{\beta}}}\cdot e^{-[t_{stress}/\eta]^{\beta}\cdot\beta\cdot\frac{t}{t_{stress}}}}{\cancel{e^{-[t_{stress}/\eta]^{\beta}}}}$$

$$\approx 1-e^{-\underbrace{\left(\beta\cdot t_{stress}{}^{\beta-1}/\eta^{\beta}\right)}_{const.}\cdot t}$$

→ exponential distribution

Conditional Weibull Distribution

- Bathtub curve consists of 3 subsets
  - Dielectric material - not stressed
    → falling failure rate
  - Dielectric material - stressed
    → constant failure rate
  - Dielectric material - end of life
    → increasing failure rate

Design for Stress

- Bathtub curve
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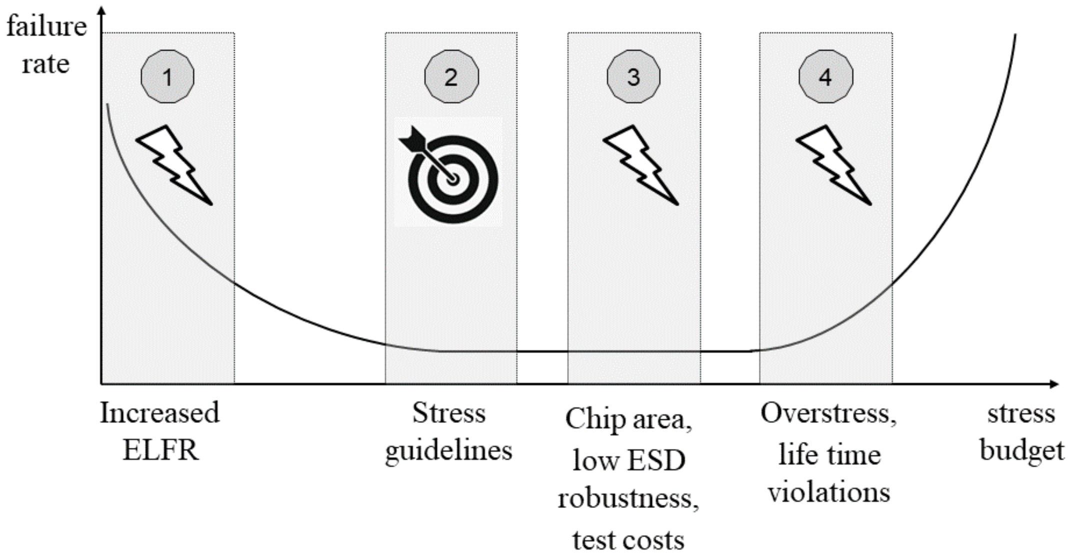
Design for Stress

- Principles
  - Increased stressed area
  - Reduced unstressed area
  - Balance between stress time and failure rate target
- HASS – High Accelerated Stress Screening
  - Based on HALT – High Accelerated Lifetime Test
  - Boundaries are determined → limit to intrinsic branch
  - Continuous optimization of stress budget

Design for Stress – Stress Guidelines

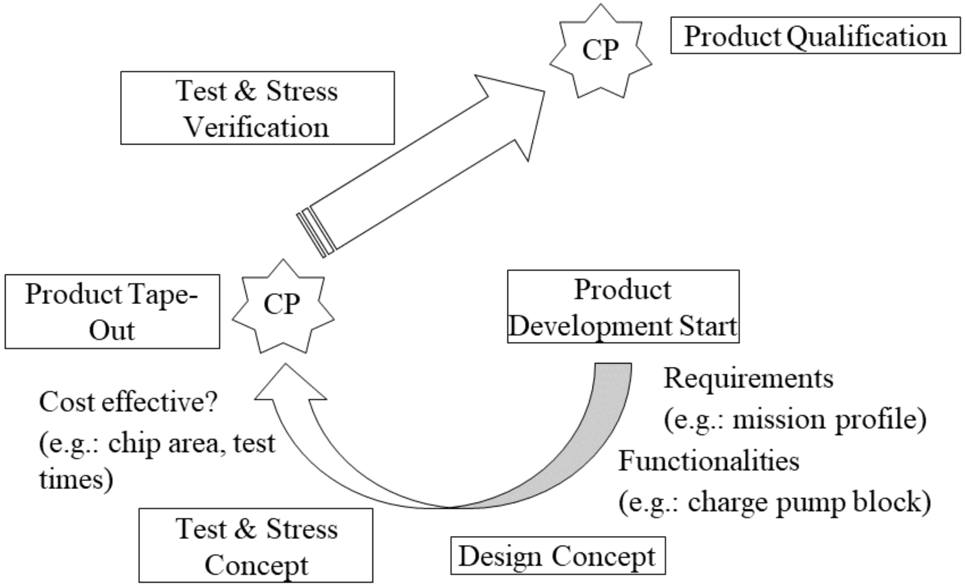


1. Lower stress bugdet / coverage increases ELFR.
2. Stress guidelines to reach the failure rate target.
3. Increased costs / lower ESD robustness.
4. Overstress triggers intrinsic branch.

Design for Stress – Stress Guidelines

- Data sources:
  - DD distributions
  - AEC Q100 stress tests
  - Test and monitoring data
  - Field performance

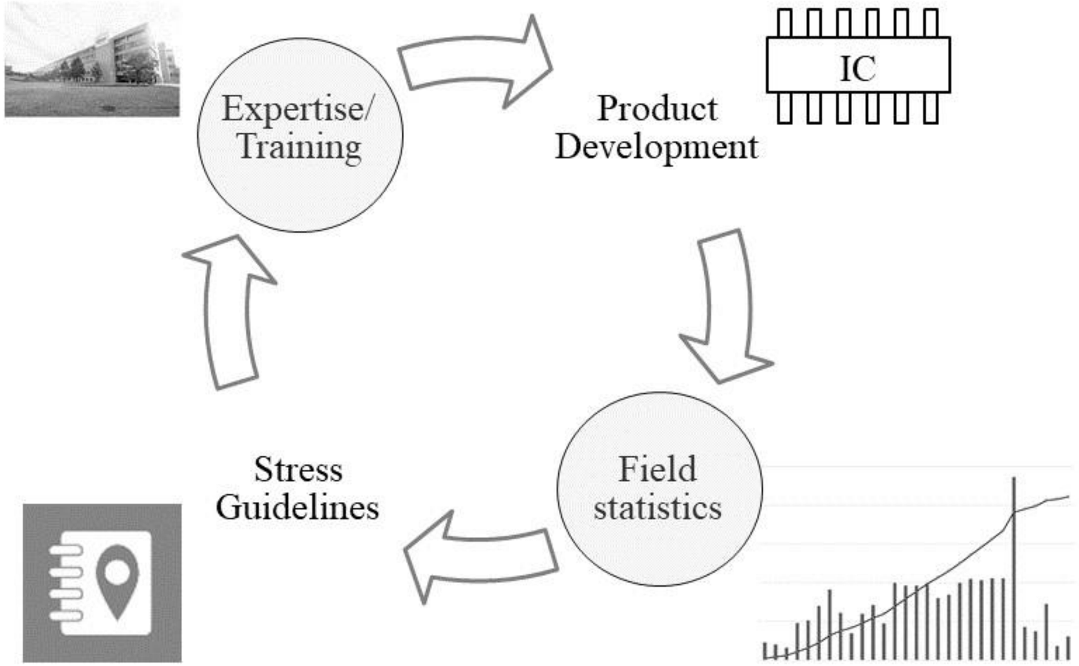
Design for Stress – Process Flow



- Integration in the product development flow of selected automotive products.
- Check points prior to tape-out and product qualification.
  - Test & stress concepts.
  - Stress compliant with DfS targets and guidelines.
  - Implementation & validation for product qualification.

Design for Stress – PDCA

PDCA Cycle



- Monitoring of field volume and performance.
- Feedback to stress guidelines and models.
- Trainings at all development sites.

Results

- Design-for-Stress (DfS) is a mature, well-established practice across Infineon’s 130 nm technology nodes.

- Continuous field-performance monitoring to refine guidelines, models, and targets.

- Today, extensive statistics for automotive DfS-labeled products with field performance << 1 ppm.

Thank you!

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