Advanced Blowing Model for Solid State Technology Fuses applied to Schurter's components

Space Passive Component Days - Noordwijk

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esa

SCHURTER
ELECTRONIC COMPONENTS

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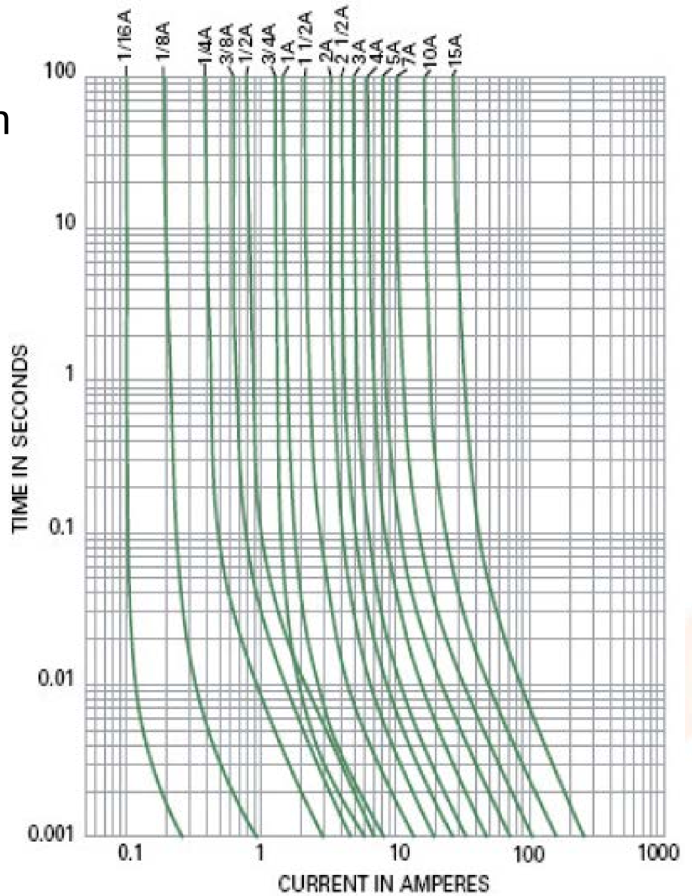
Contents

1. Introduction and background (1/4)

- Do we need fuse models?
- Aren’t fuses cheap? Do we really use so many fuses on a satellite?
  - One space-qualified fuse can cost ~**300€.**
  - Telecommunications Satellites from Eurostar-3000 series can require between **400 and 500 fuses.**
- Need to reduce the number of destructive tests:
  - For financial reasons.
  - For security reasons: over-voltages and over-currents that can stress or damage other equipment.
- Yes, we definitely need fuse models.

1. Introduction and background (2/4)

- How can we model a fuse?
  - It should be very simple: a fuse blows after a certain time for a given current.
  - Time = f(Current) following an $I^2 \cdot t$ relationship
- But:
  - What happens to the voltage and current between the time the short-circuit appears and the time the fuse blows?
  - What happens during the arcing phase? Is there an infinite resistance all of a sudden?
  - How can we predict over-voltages?

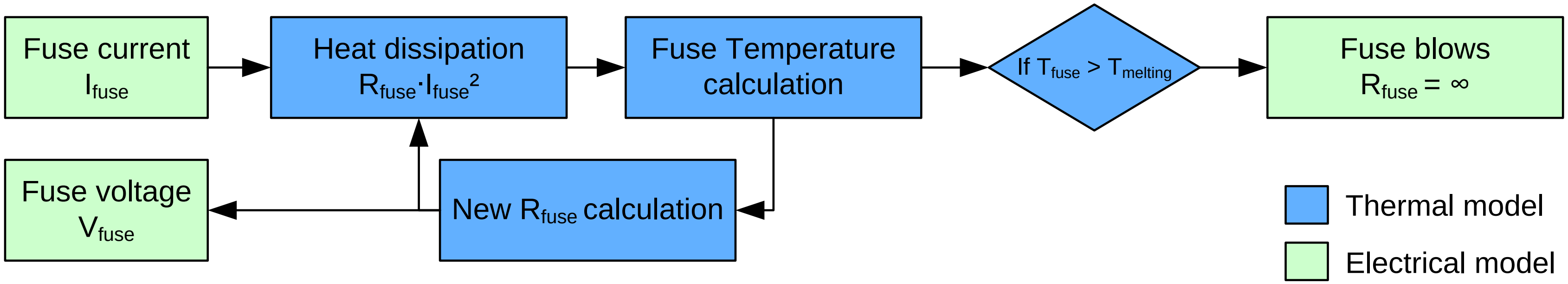


Source: LITTELFUSE

- We need an electrical model that takes into account the thermal behaviour.

1. Introduction and background (3/4)

- Simulation principle for the thermo-electrical model:



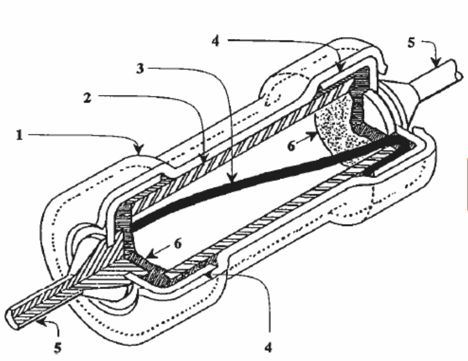
- How to perform the thermal model of a fuse?
  - It will depend on:
    - The geometry of the fuse section
    - The materials used
  - Since it will be implemented in SPICE environment and it requires to model temperature evolution over time, the model will be composed of resistances and capacitances.

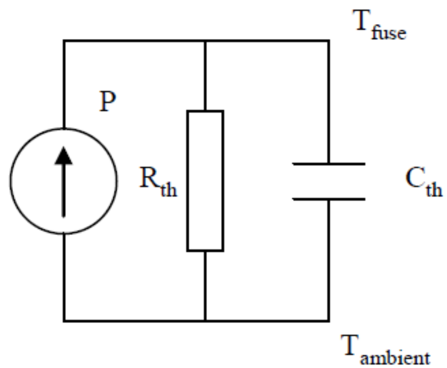
1. Introduction and background (4/4)

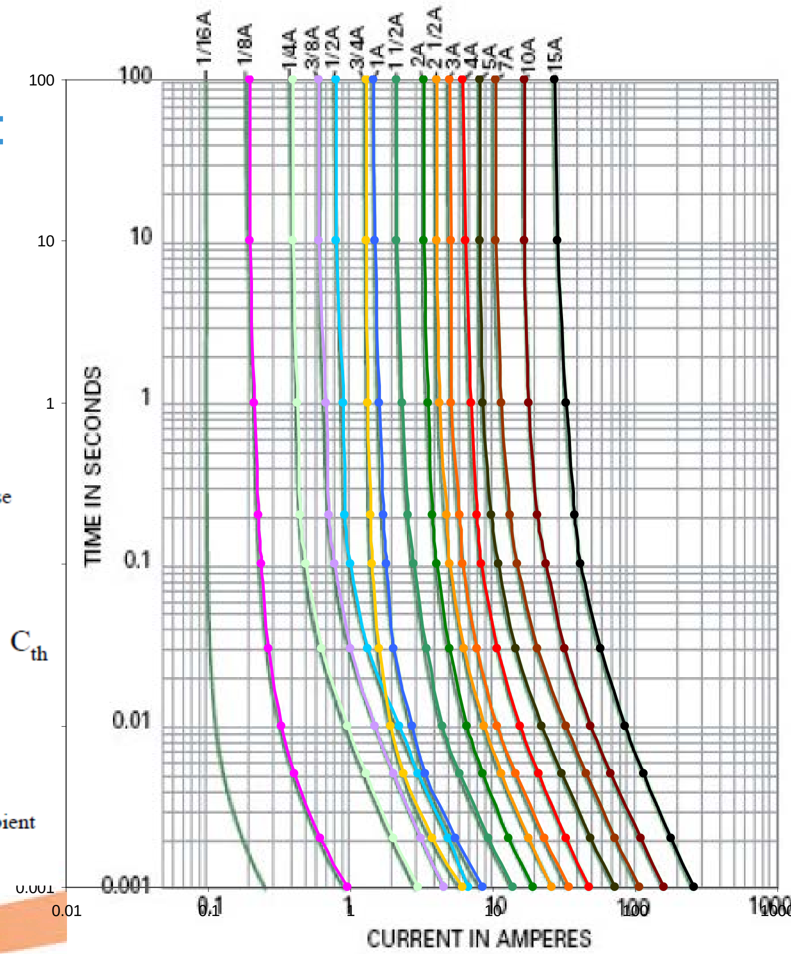
- <u>Example:</u> Wire fuse technology

- LITTELFUSE FM08 - Fuse composition:
  - Filament wire made of nickel, copper-silver or pure copper depending on the current
  - Vacuum vessel surrounding the wire

Source: LITTELFUSE







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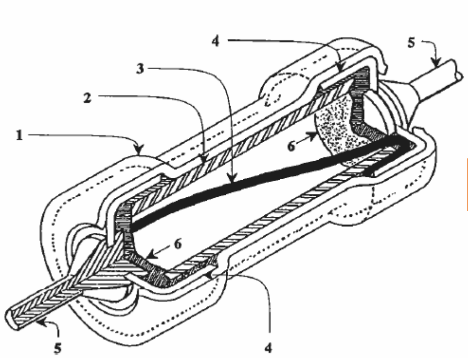
2. Solid State Fuse modelling (1/9)

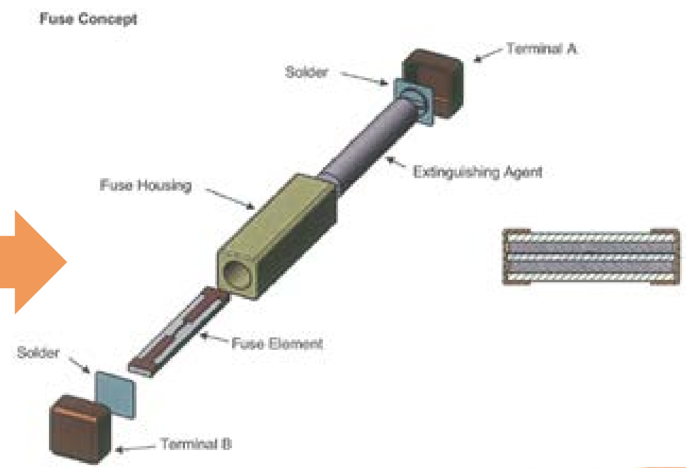
- Completely different geometry: no axis of symmetry
  - No single material in a vacuum vessel.
  - Different materials and non-uniform cross-section.

FM08

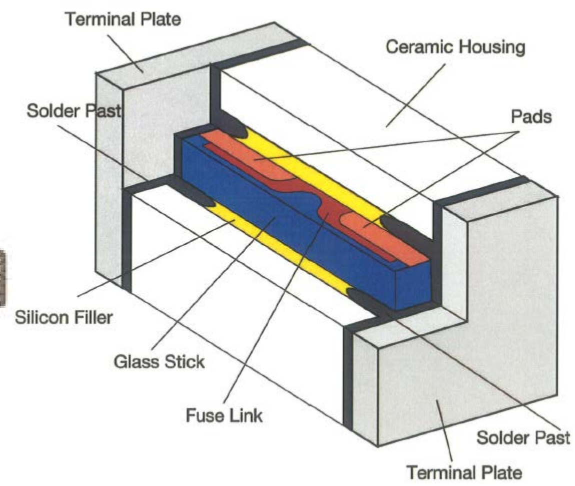


Source: LITTELFUSE

HCSF



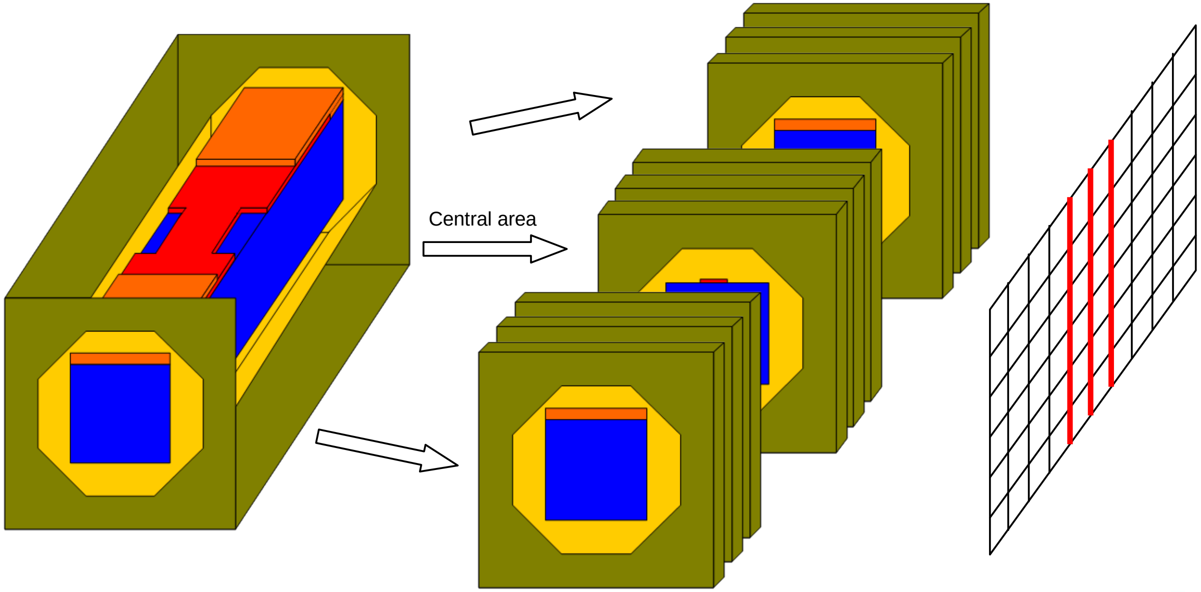
MGA-S



Source: SCHURTER

2. Solid State Fuse modelling (2/9)

- New approach: from a 3D model to 2D slices



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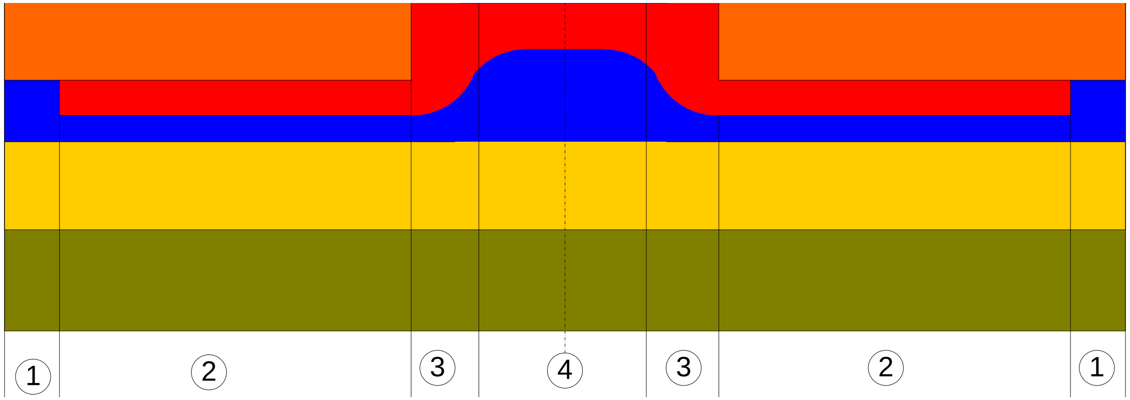
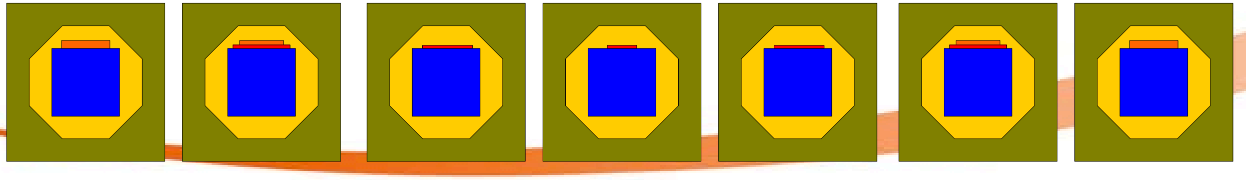
2. Solid State Fuse modelling (3/9)

- Each 'slice' corresponds to a different cross-section
- The electrical resistance is not uniformly distributed anymore
  - Each section will have a different electrical resistance
  - It can be deduced from the changing geometry

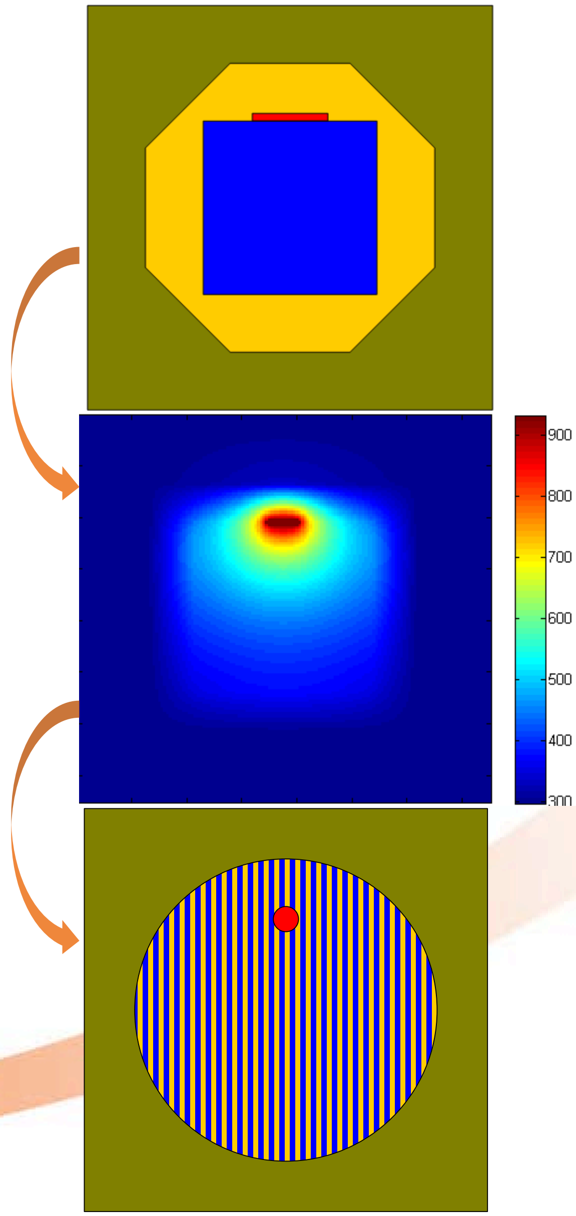


Section	Resistance %
1	2.71%
2	13.97%
3	10.16%
4	46.33%
3	10.16%
2	13.97%
1	2.71%
TOTAL	**100.00%**



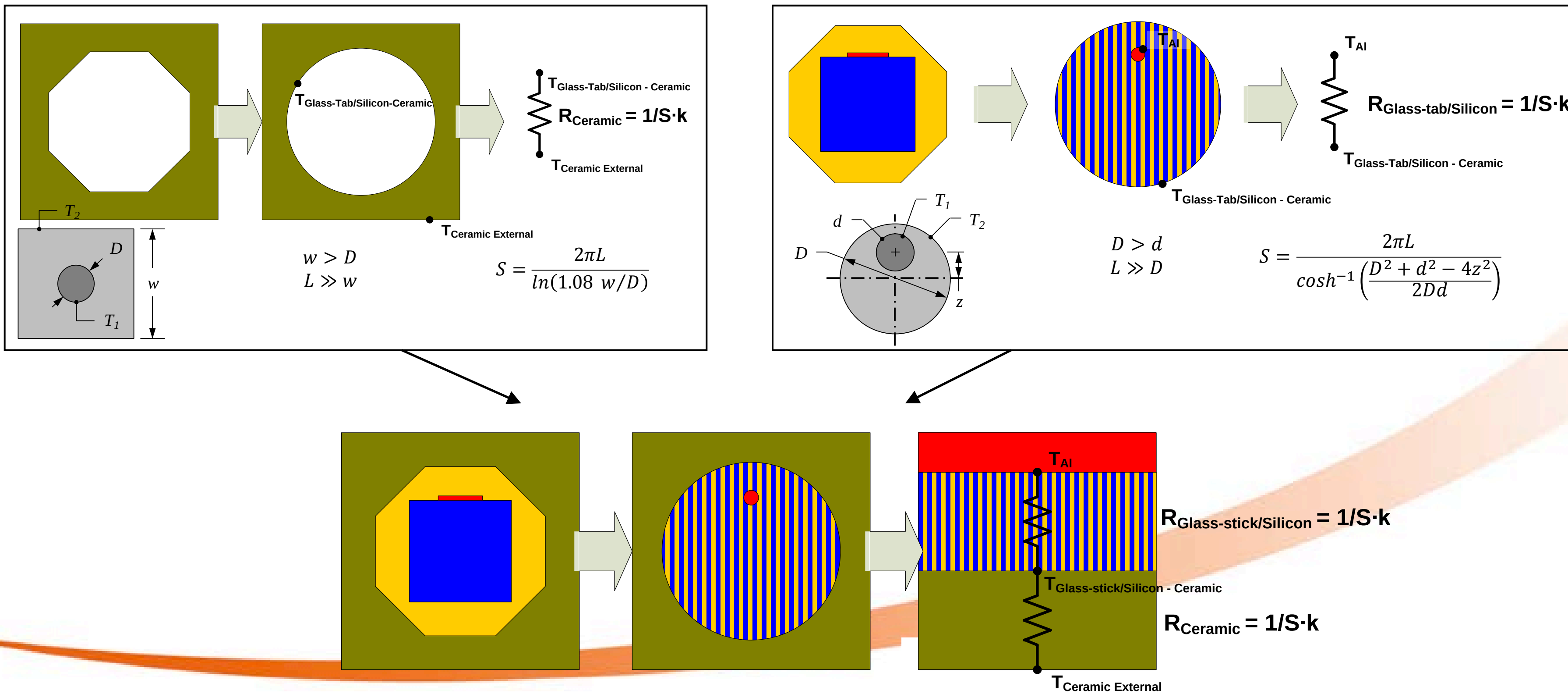
2. Solid State Fuse modelling (4/9)

- Preliminary analysis of the different sections:
  - FEM analysis of the steady-state temperature distribution
  - Low impact of the ceramic element (green)
  - Radial temperature distribution starting from the fuse element
- Assumptions:
  - Fuse element (red) assumed to be a cylinder (equivalent surface for heat exchange).
  - Both the glass-tab (blue) and the silicone (yellow) mixed as a single material with a cylindrical shape (physical properties weighted).
  - Copper and aluminum coupled in parallel configuration, will be assumed as circular with also a mixed material.



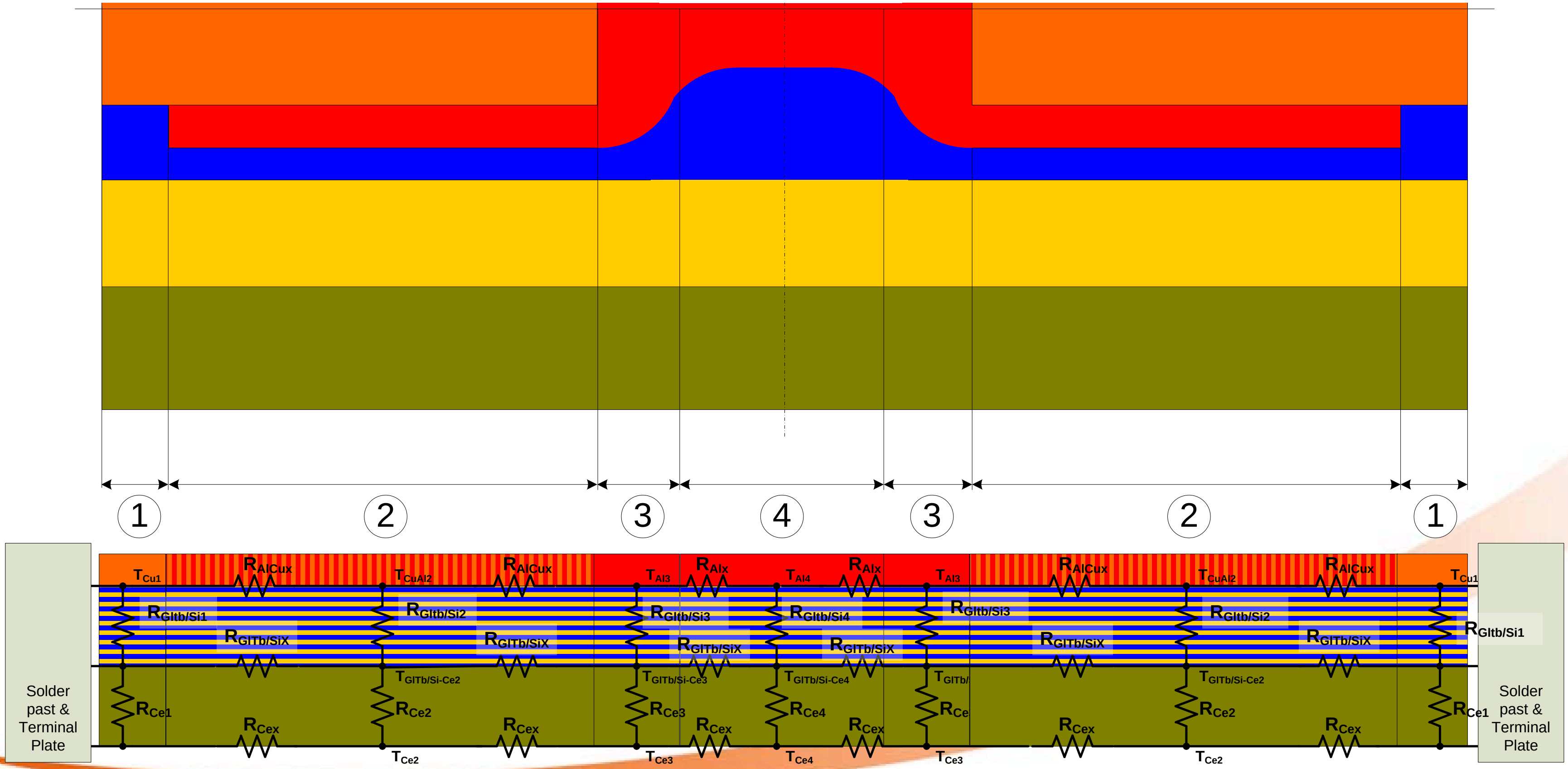
2. Solid State Fuse modelling (5/9)

- How to calculate equivalent electrical resistances in a 2D thermal conduction situation?
  - Use of **Shape Factors** [Incropera – DeWitt and Sunderland – Johnson]



2. Solid State Fuse modelling (6/9)

- Once the shape factors are applied to every section, those can be connected through 'horizontal' thermal resistances



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2. Solid State Fuse modelling (7/9)

- Each layer can therefore be associated to a sort of ‘finite element’ composed of:
  - A ‘vertical’ thermal resistance calculated using shape factors and divided in two equal parts.
  - An horizontal thermal resistance calculated using the physical properties and the volume of the element.

$$R_{CeX} = \frac{L_X}{k_{Ce} \cdot A}$$

  - A **<u>thermal capacitance</u>** calculated with the same parameters.

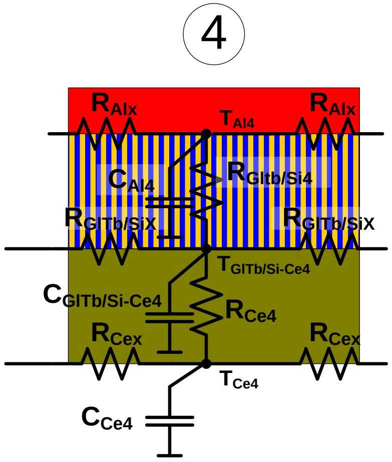
$$\begin{cases} C_{Al4} = C_{Al} \cdot V_{Al4} \cdot \rho_{Al} \\ C_{GlTb/Si-Ce4} = C_{GlTb} \cdot V_{GlTb4} \cdot \rho_{GlTb} + C_{Si} \cdot V_{Si4} \cdot \rho_{Si} \\ C_{Ce4} = C_{Ce} \cdot V_{Ce4} \cdot \rho_{Ce} \end{cases}$$

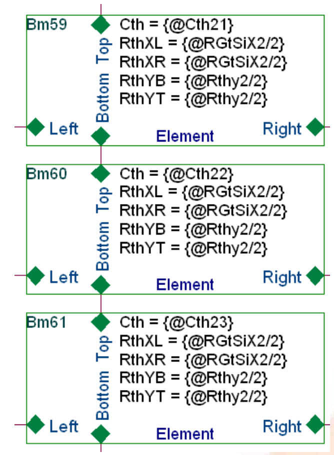
    - Where:

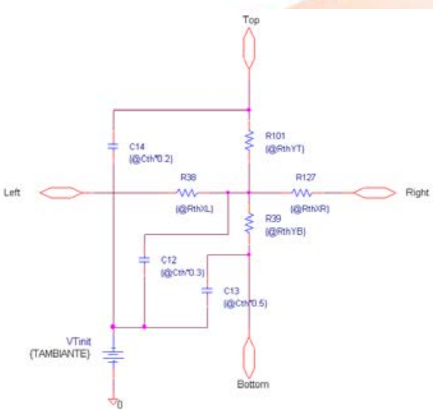
      C is the Heat capacity of each material in [J/g.K]

      V is the volume in [cm^3]

      ρ is the density in [g/cm^3]

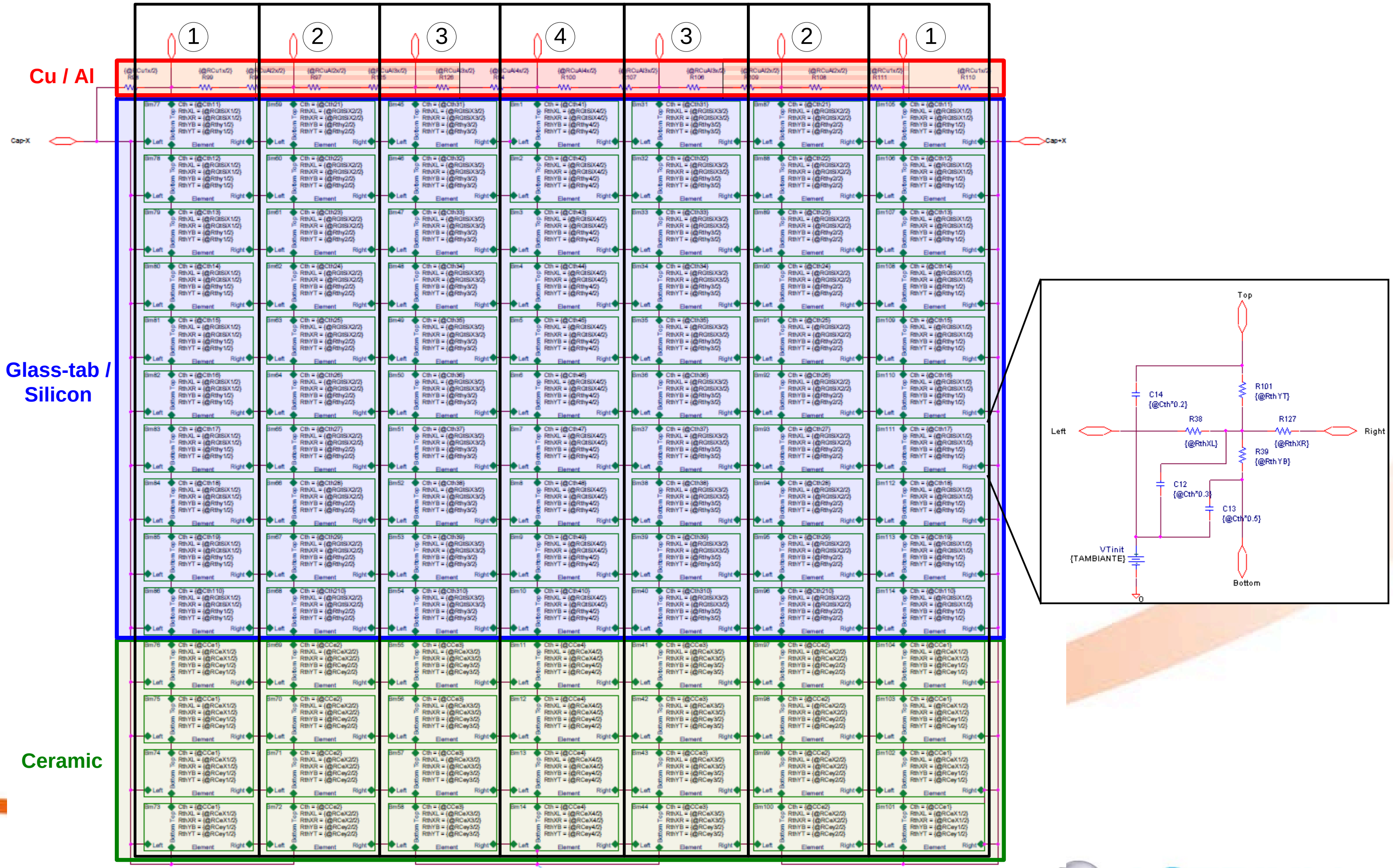






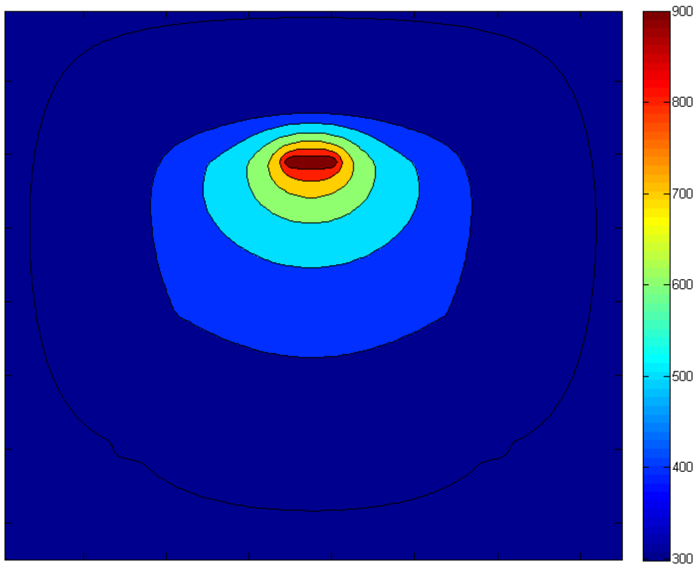
2. Solid State Fuse modelling (8/9)

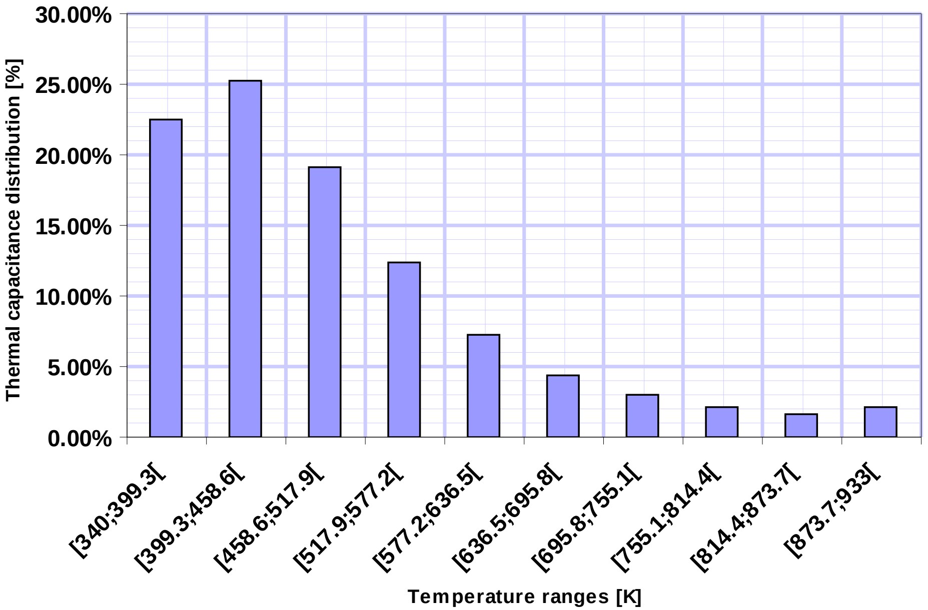
- Dividing the current layers into several increases the resolution and the accuracy of the time results.



2. Solid State Fuse modelling (9/9)

- If we divide one layer into several ones, how do we distribute the capacitances?
  - From the FEM analysis, thermal capacitance can be derived for each temperature step (constant).

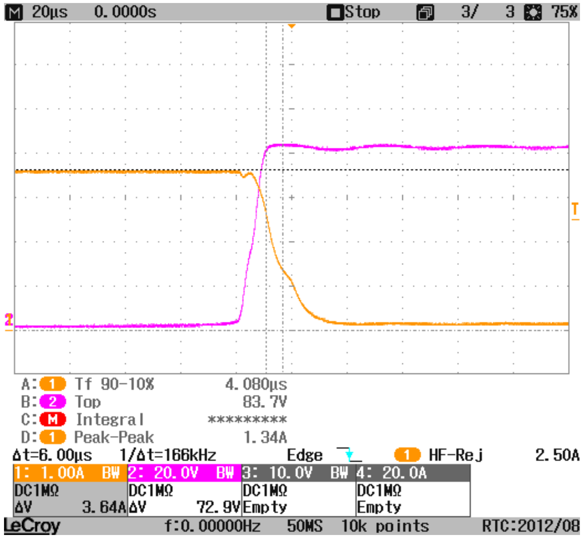




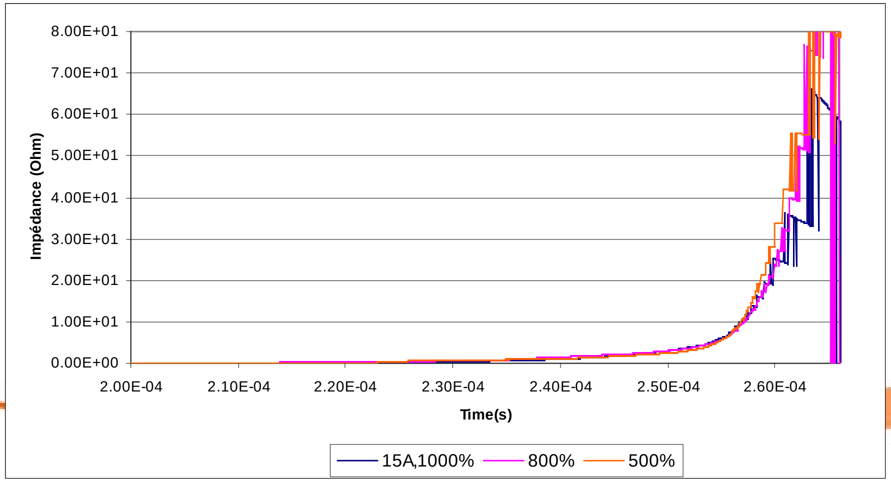
Contents

3. Arcing modelling (1/3)

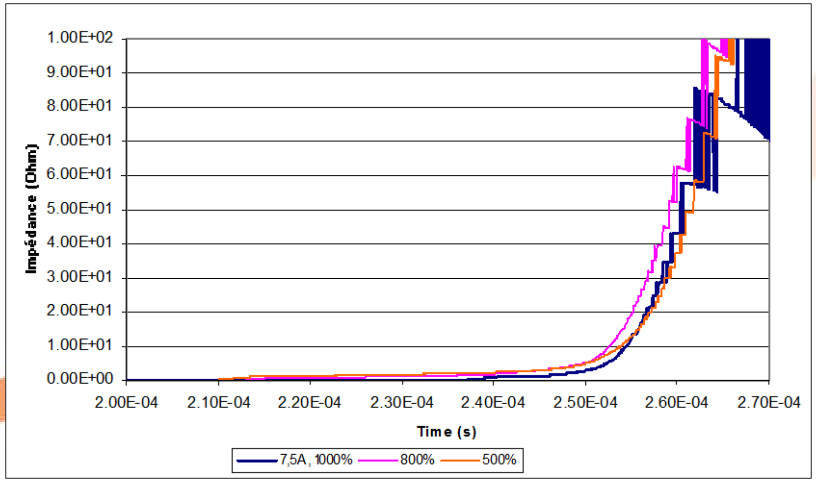
- Arcing tests performed by Schurter:
  - Similar current and voltage profiles for the MGA-S and HCSF (almost linear),
  - Same resistance evolution for one fuse model at different rated currents.
- Different approaches tested: exponential, polynomial…



HCSF 15A test results



HCSF 7.5A test results



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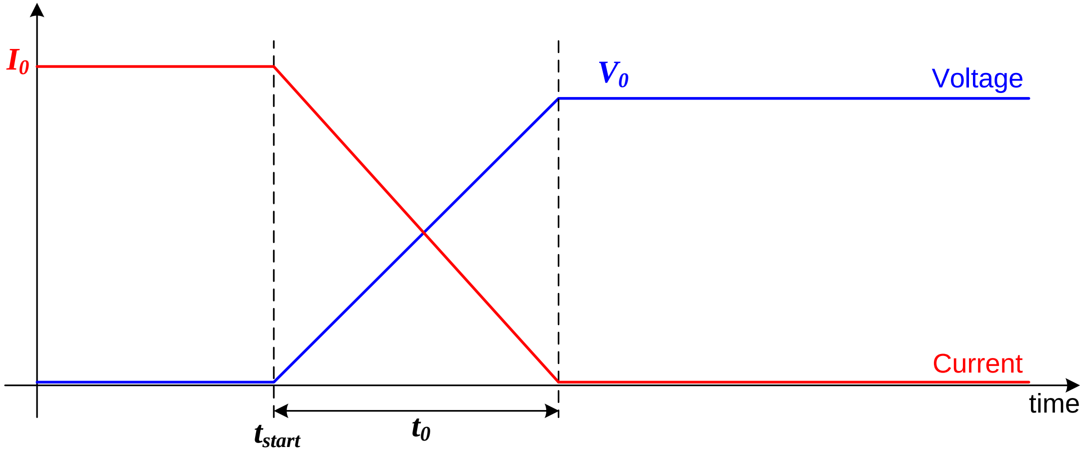
3. Arcing modelling (2/3)

- Fuse arcing theory:
  - We assume from the measurements that voltage and current evolve linearly with the following profiles:



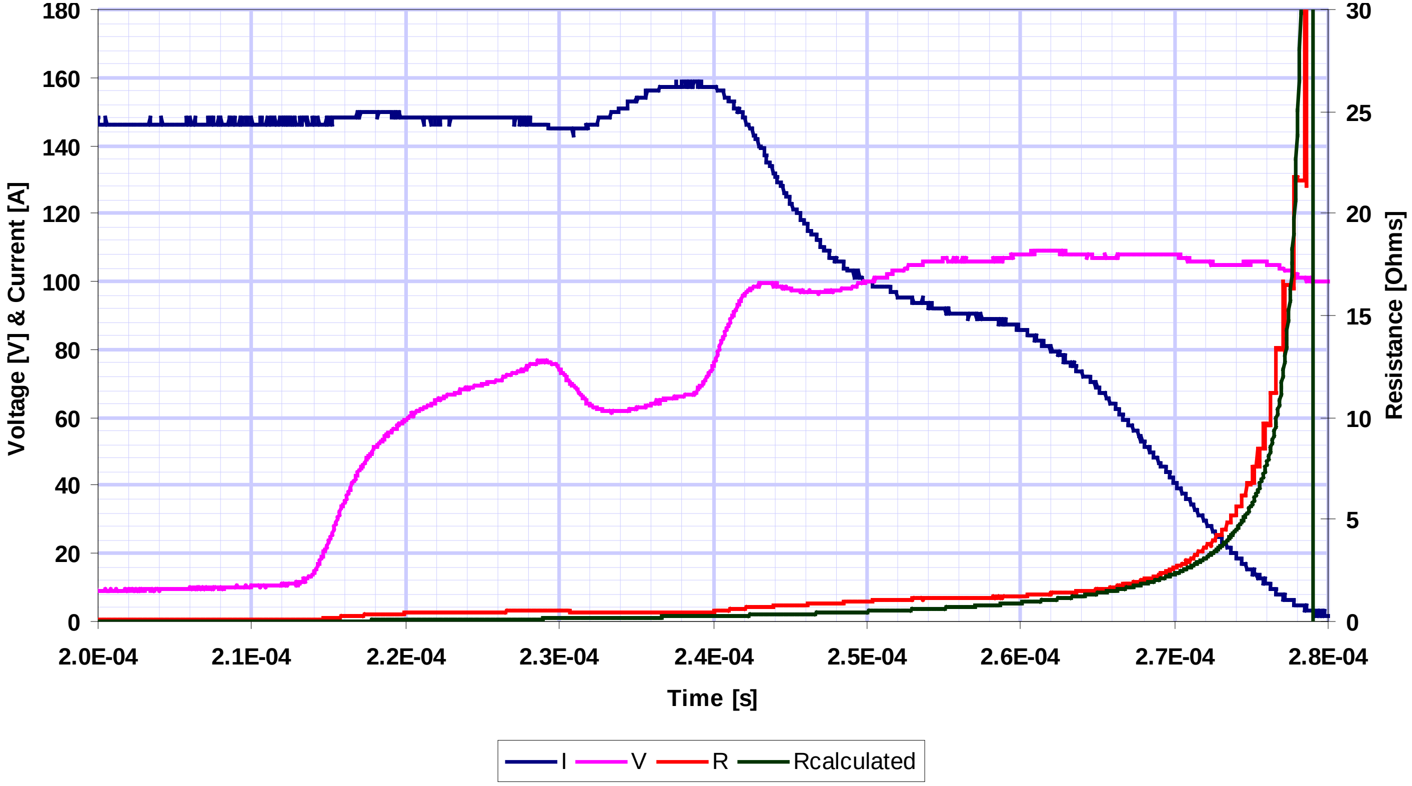
- Resulting equation for the resistance:

$$\begin{cases} I = I_0\left(1 - \dfrac{t - t_{start}}{t_0}\right) \\ V = V_0\left(\dfrac{t - t_{start}}{t_0}\right) \end{cases}$$

$$\boxed{R = R_0 \dfrac{\left(\dfrac{t - t_{start}}{t_0}\right)}{\left(1 - \dfrac{t - t_{start}}{t_0}\right)}}$$

3. Arcing modelling (3/3)

- Arcing test result on HCSF 15A at 1000%
  - with the real resistance evolution (red)
  - and the one from the model (dark green)

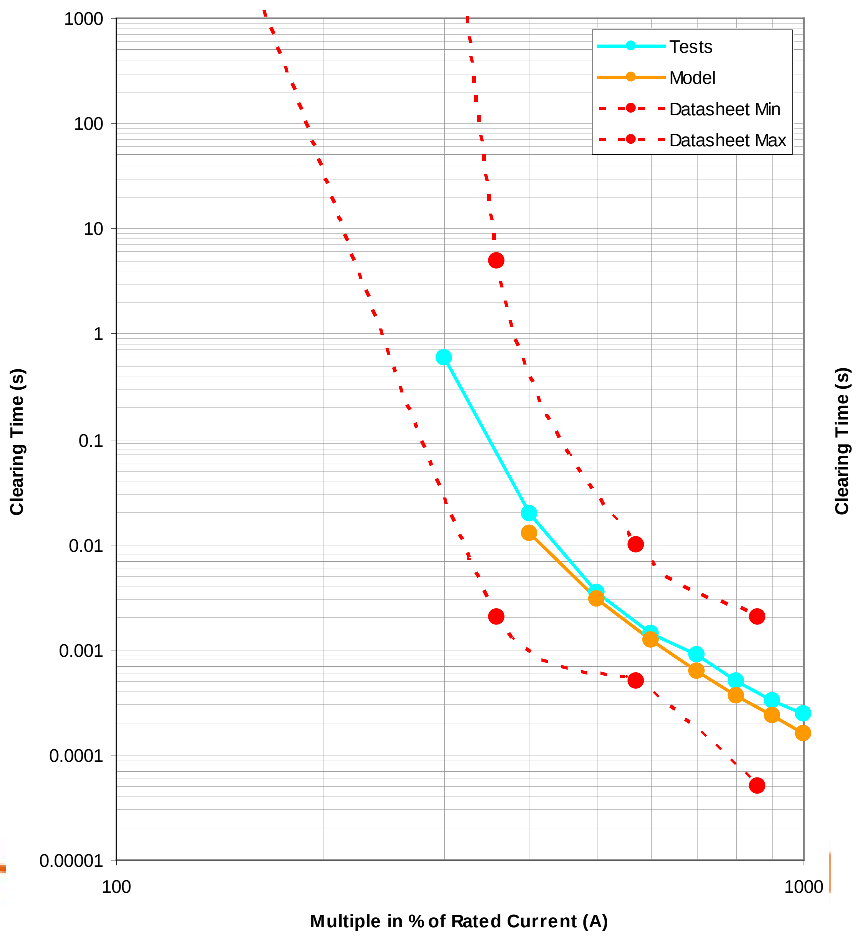


Contents

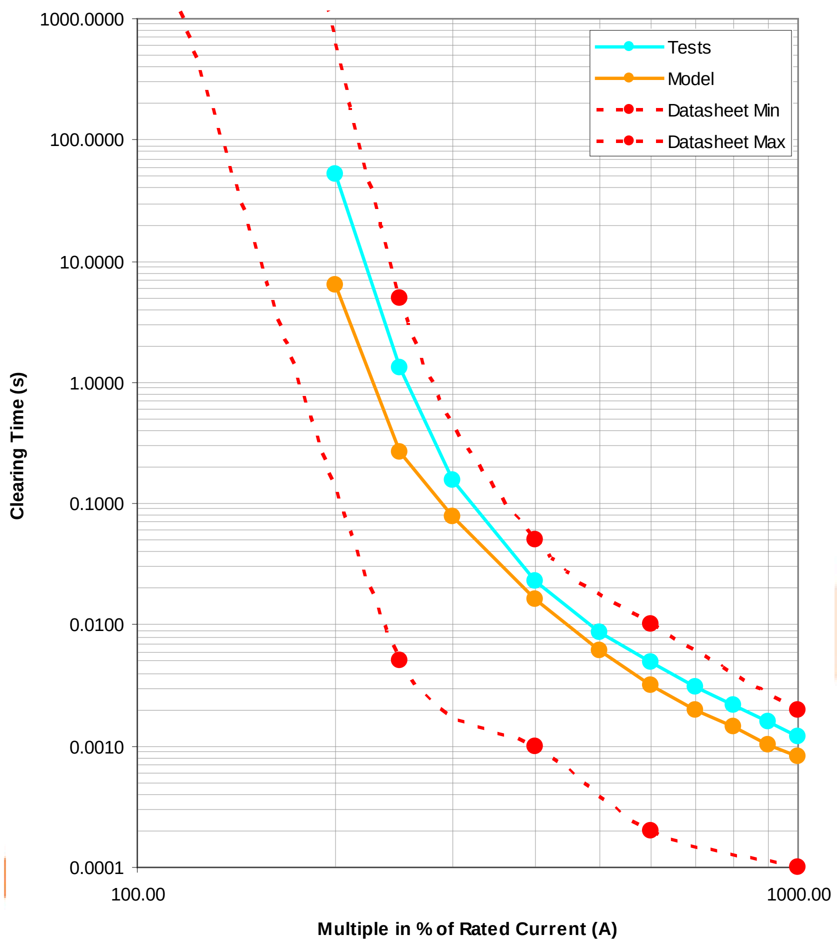
4. Test correlation results (1/5)

- Test correlations Phase 1: blow time at different currents :

MGA-S 1.4A



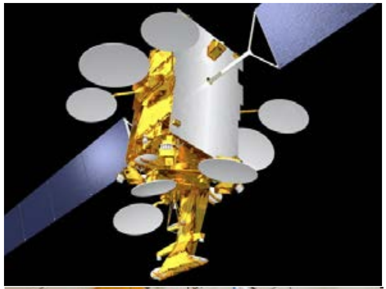
HCSF 7.5A

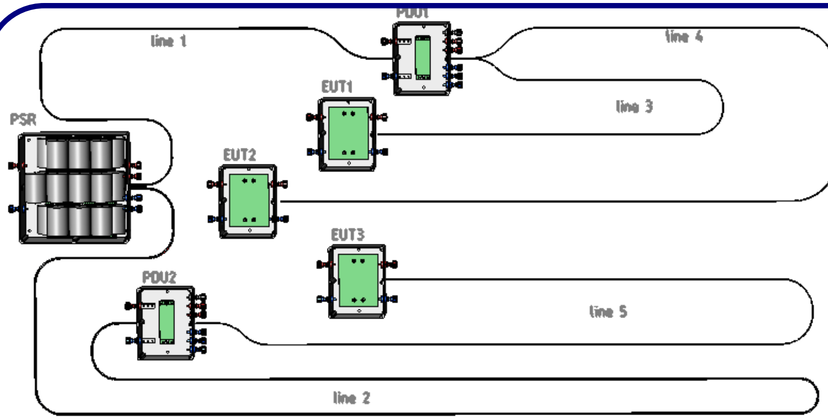


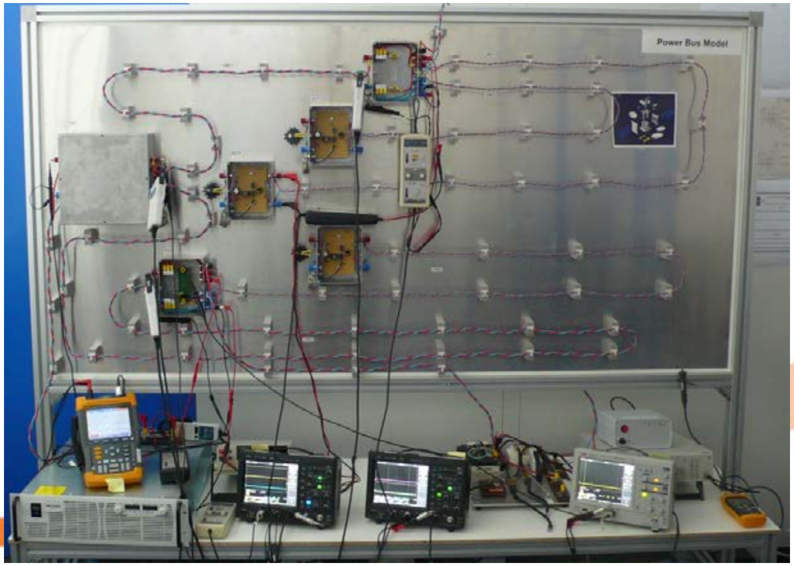
4. Test correlation results (2/5)

- Test correlations Phase 2: Power bus setup

E3000
Power bus model





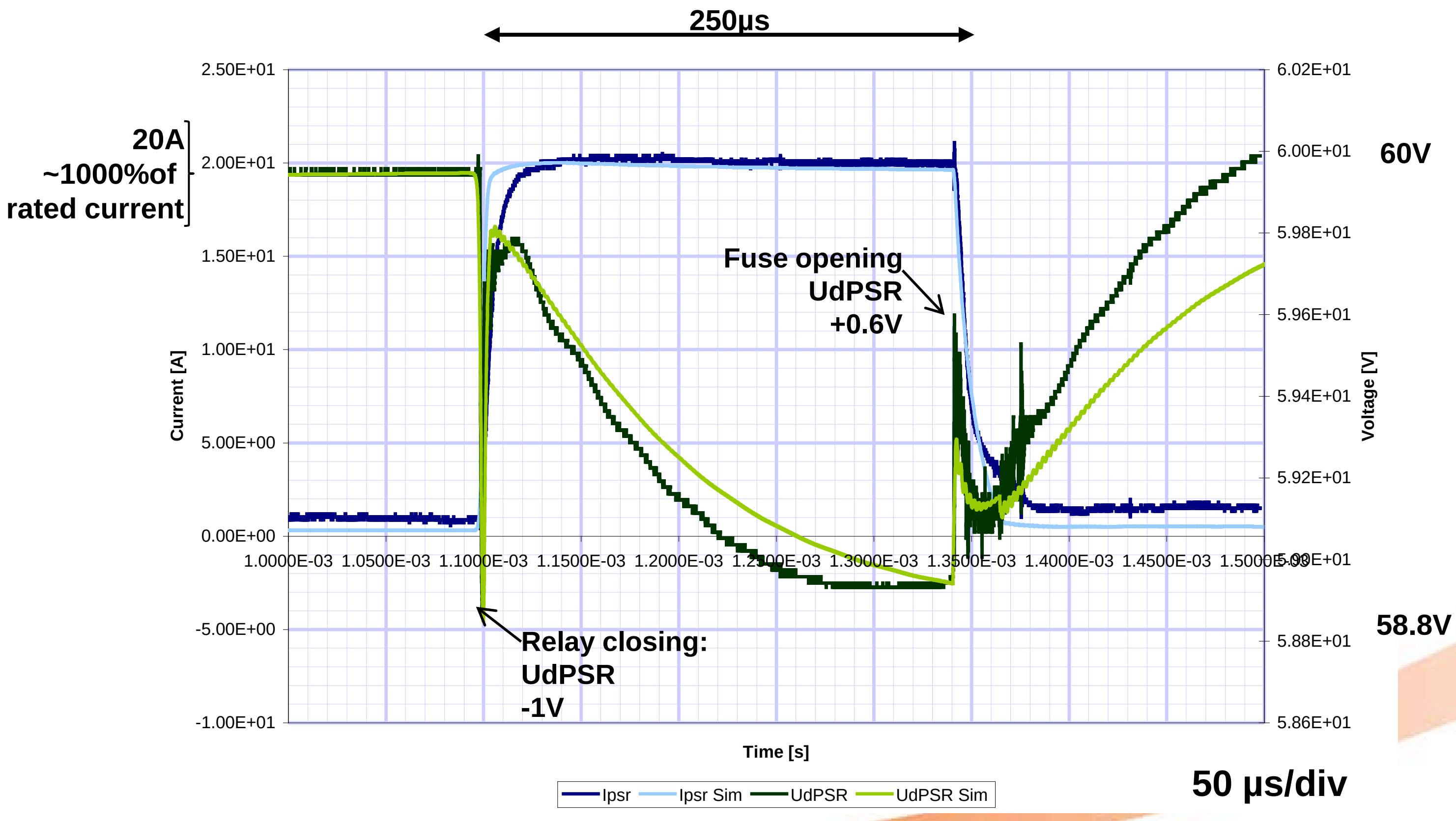


Simplified
Power bus model

- **1 PSR:** Power Supply Regulator
- **2 PDU:** Power Distribution Unit
- **3 EUT:** Equipment Under Test

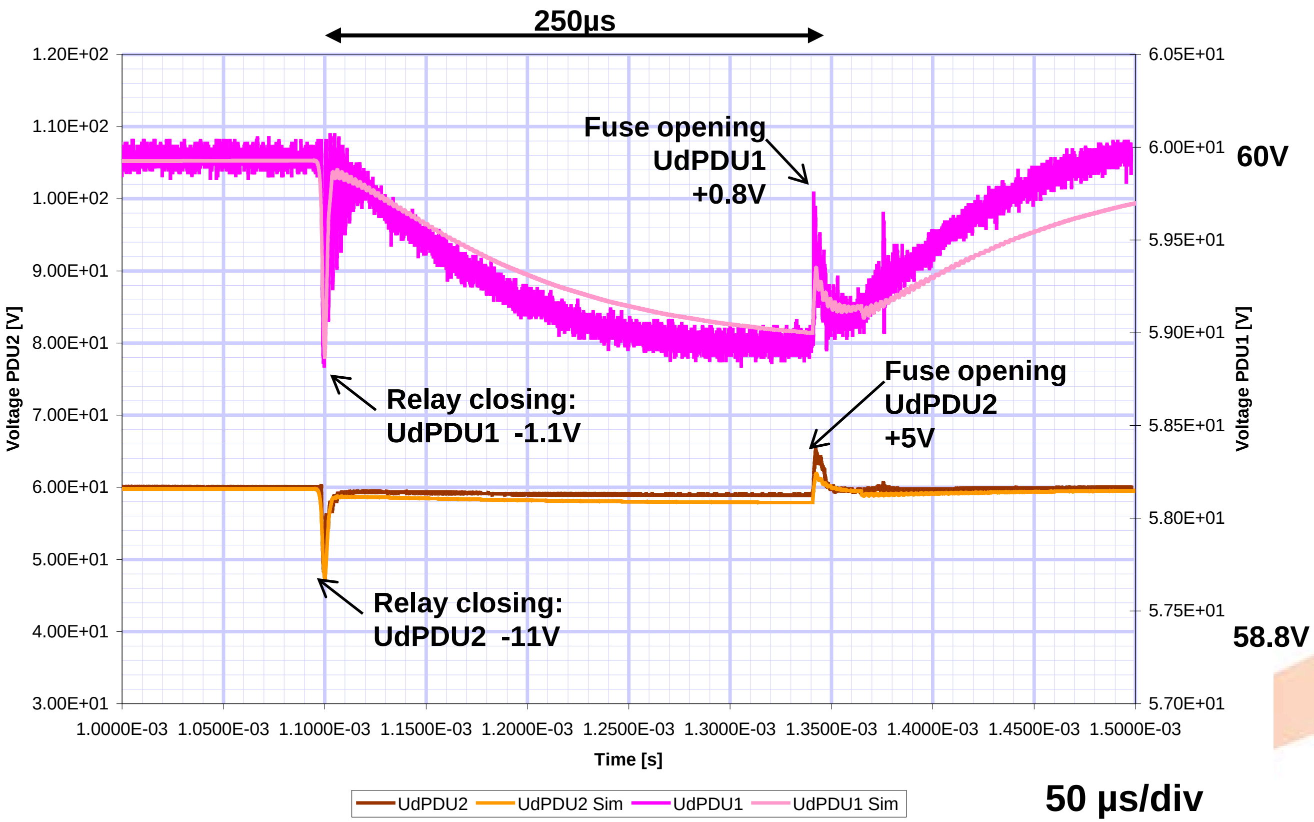
4. Test correlation results (3/5)

- Test correlations Phase 2: Power bus setup with MGA-S 2.1A
  - PSR current and differential voltage at PSR's output with tuned parameters



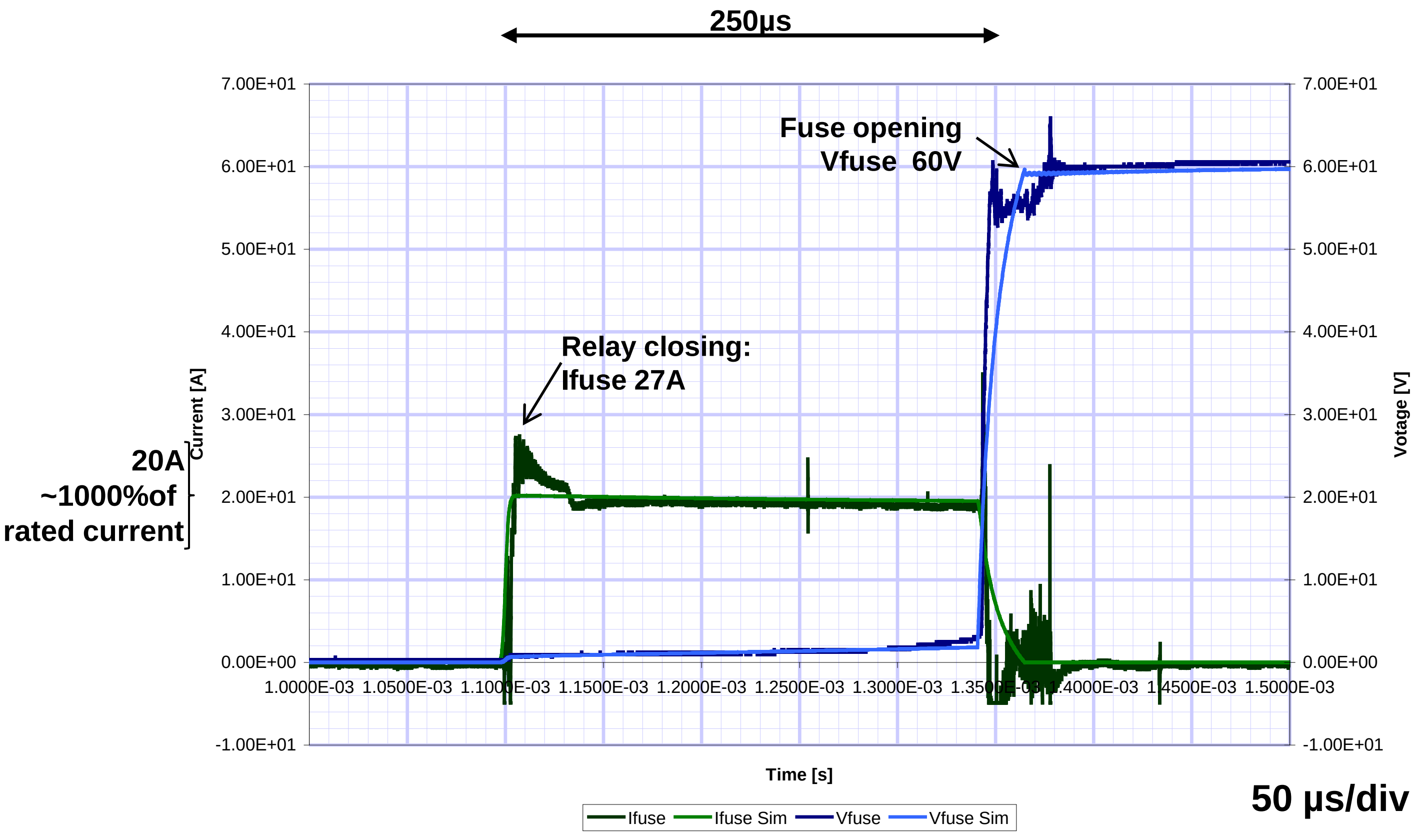
4. Test correlation results (4/5)

- Test correlations Phase 2: Power bus setup with MGA-S 2.1A
  - Differential voltages at PDU1 and PDU2 outputs with tuned parameters



4. Test correlation results (5/5)

- Test correlations Phase 2: Power bus setup with MGA-S 2.1A
  - Fuse current and voltage with tuned parameters



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5. Conclusion

- The main results of the study are:
  - Solid State technology fuses can be modeled as well as the wire technology fuses (higher precision with higher currents).
  - The models are very responsive to any variation in terms of cold resistance, materials or design.
  - Shape factors approach requires to have access to many fuses' characteristics (materials, dimensions…) from the manufacturer and many tests for accurate correlations.
  - Approach is perfectly valid for system level tests, since it does not need high-performance processors or simulation time. However, more accurate simulations could be obtained with dedicated CAD and thermal FEM software, also useful for fuse design and development.
  - Arcing modeling looses accuracy with currents much higher than 1000%.

Thank you for your attention.