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6/3/06

CALICE Thermal Simulations

Aim to predict the temperature values and gradients within the CALICE structure.

Use spreadsheet estimates and fast simulations that can easily be modified. At this stage in design, trying many variants is more important than high accuracy.

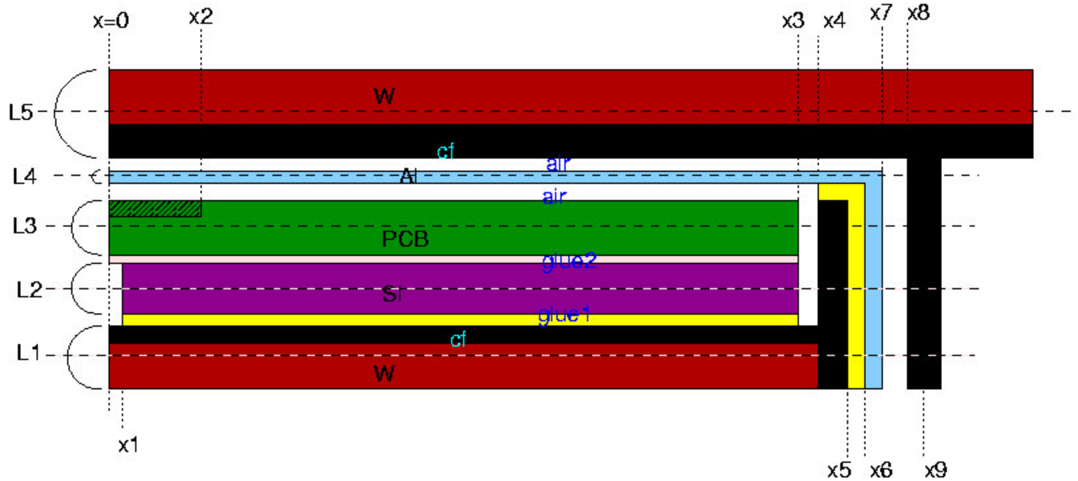
The problem: Complex cell structure, cell details may influence thermal properties. Main temperature gradients are over long distances → many cells → many nodes → slow.

Solution: Use detailed models to calculate an average bulk conductivity of the structure in the three principle directions; X (across slab), Y (along slab), Z (perpendicular to slab). Use these values, together with chips/m^3 and chip power as inputs to model of whole module.

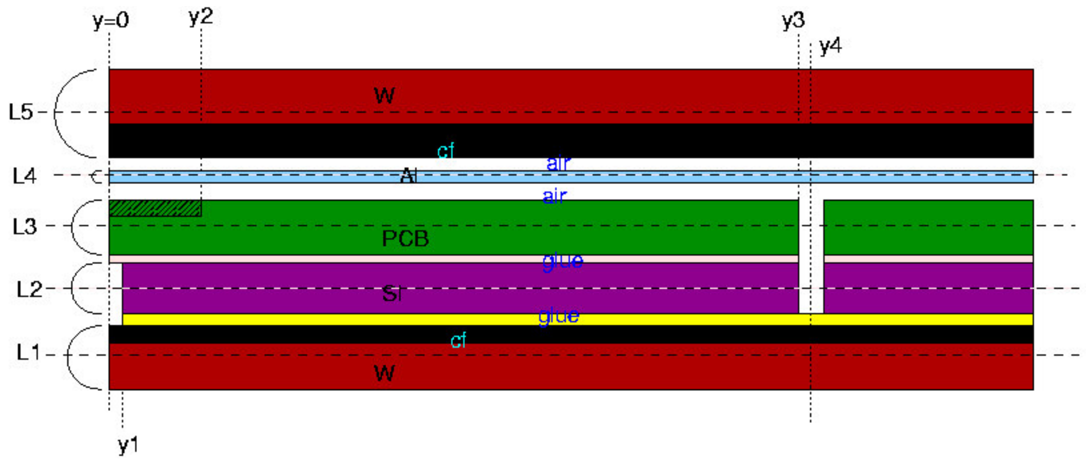
Cell layout

Layout is based on presentation of Marc Anduze of 9/6/2005 plus some guesses.

X-Z section



Y-Z section



Guesses for:

carbon fibre thickness 0.3 mm and 1.0 mm

glue1 thickness 0.1 mm

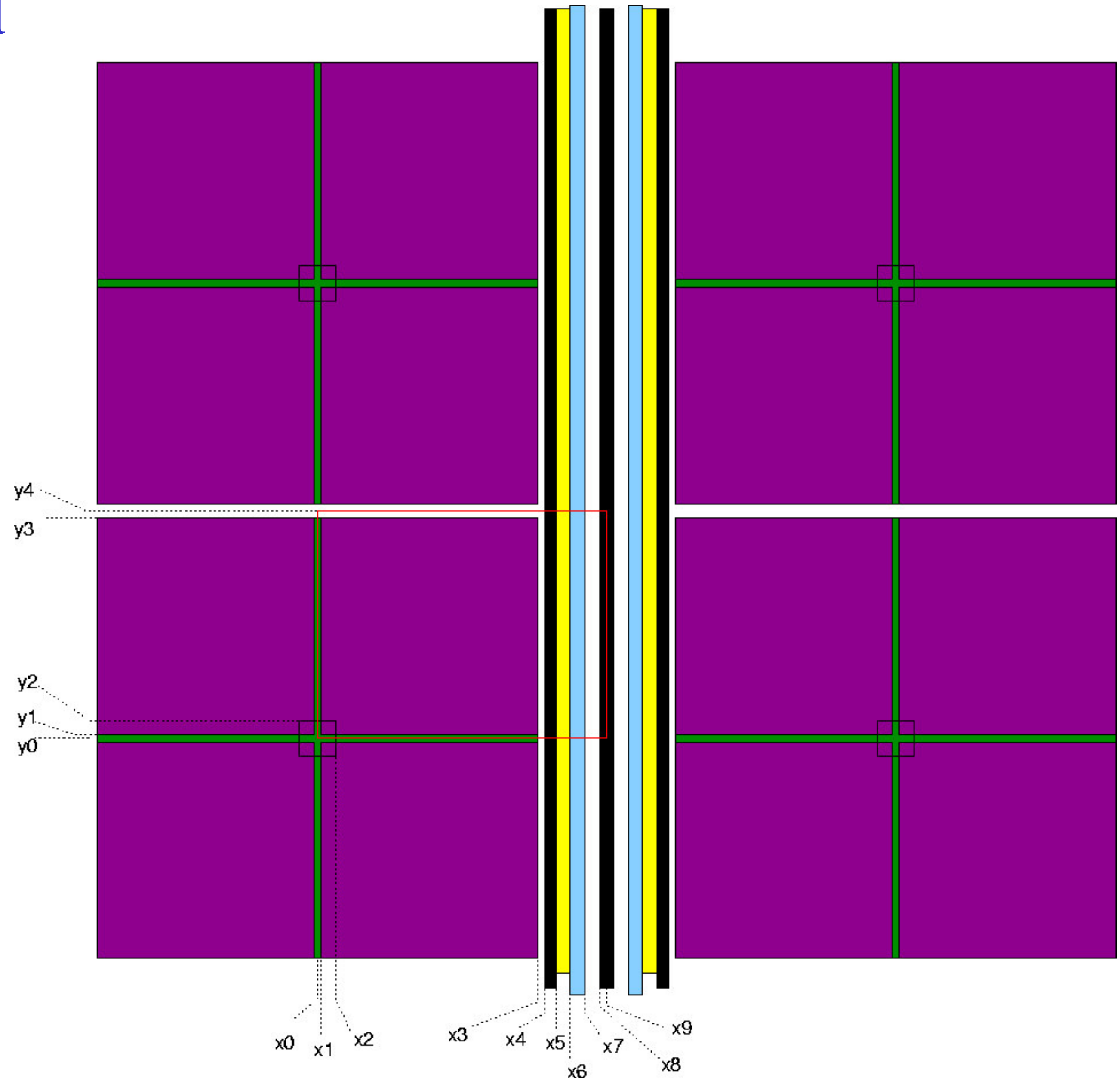
air gaps (clearance) 0.5 mm in X, 0.2 mm in Z.

Unit cell contains half of each tungsten layer.

Layout continued

X-Y
section

Unit cell shown by
red box.



Thermal conductivities

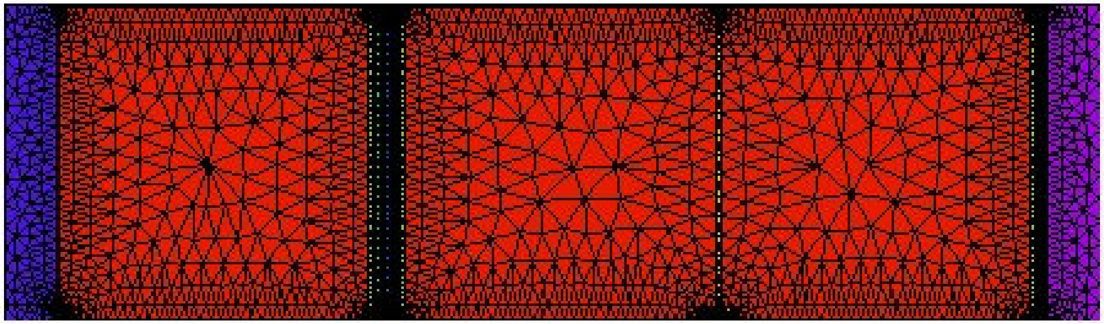
Based on standard tables plus some guesses.

Section from FlexPDE code:

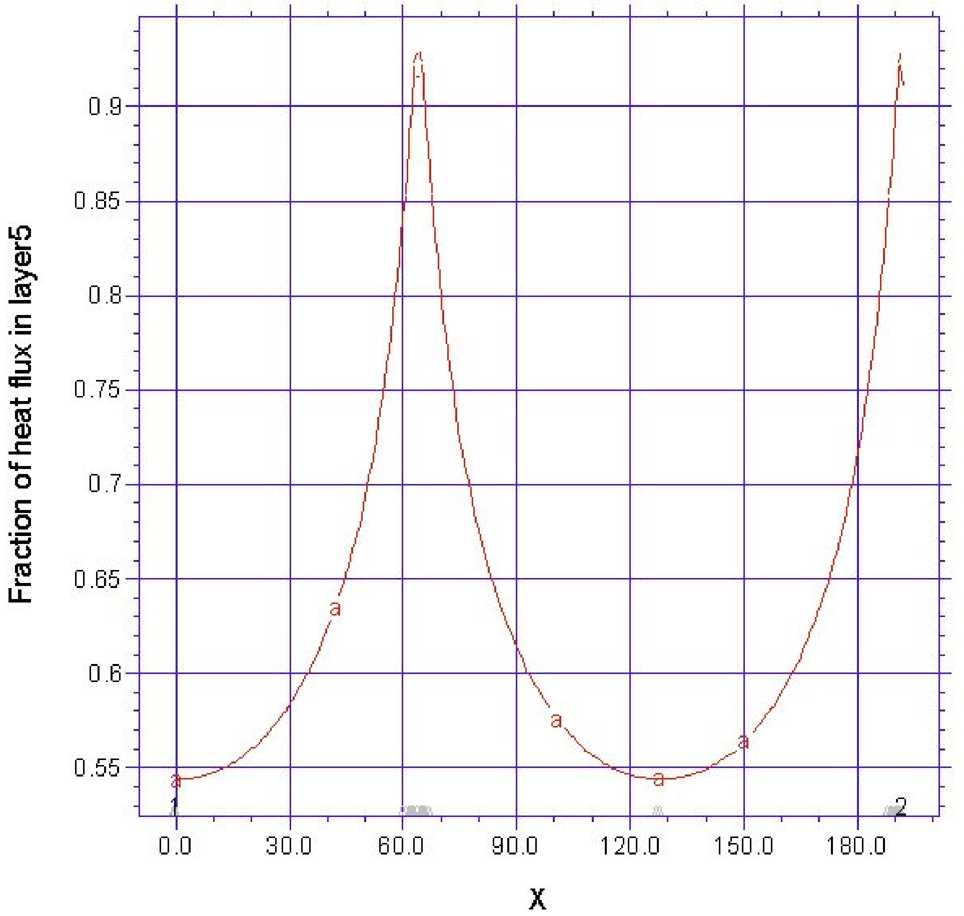
```
C_W     =   0.177    { conductivity of tungsten    W/(mm*K)}
C_Si    =   0.168    { silicon }
C_Al    =   0.180    { aluminium }
C_N     =   0.000024 { nitrogen or air }
{  below here are guesses }
C_g_SiH = 0.0002     { glue  Si to H }
C_g_AlH = 0.0002     { glue Al foil to H }
C_g_SiPCB = 0.010    { glue Si to PCB }
C_CF_in    = 0.05    { carbon fibre in-plane }
C_CF_out = 0.005     { carbon fibre out-of-plane }
C_PCB_in = 0.01      { PCB in-plane }
C_PCB_out = 0.002    { PCB out-of-plane }
```

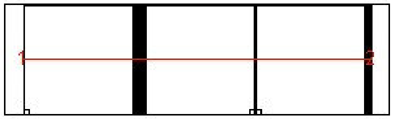
FlexPDE model for Cx

Cooling in the x direction seems unlikely, but I calculated Cx anyway.

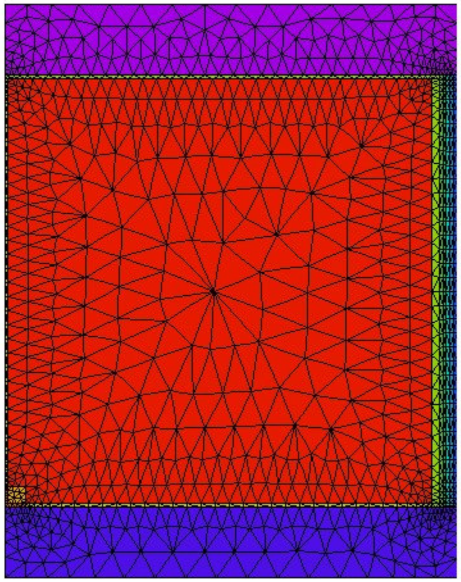


Layer 5 is the alveolus structure. It carries 93% of the heat at the slab boundaries but only 54% at the slab mid point.

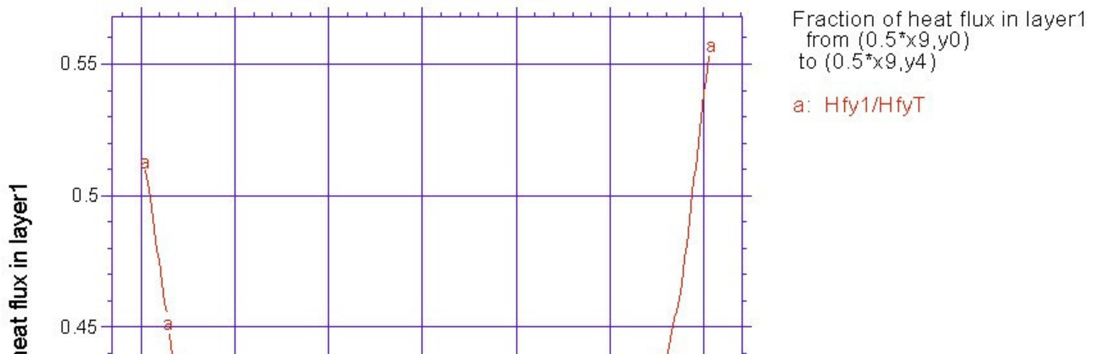


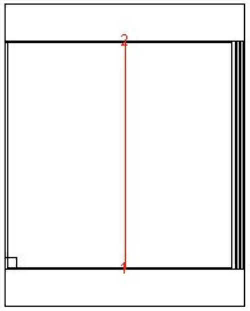


FlexPDE model for Cy



Conductivity in this direction is fairly trivial. Nearly all the heat flows in the two tungsten layers.

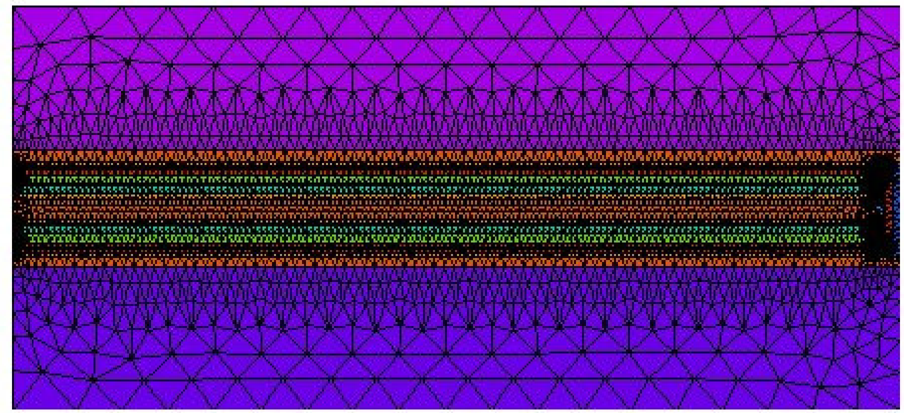




Layer 1 is the tungsten/CF in the slab. It carries about 40% of the heat.

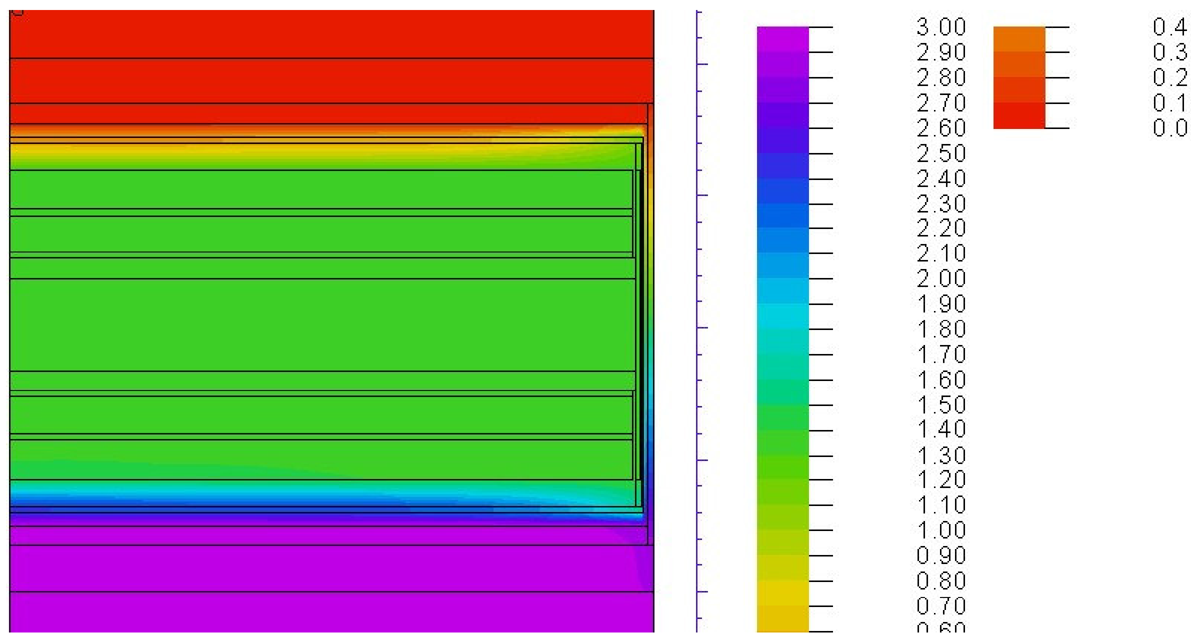
About 38% is in the alveolus tungsten/CF and the remainder mainly in the silicon.

FlexPDE model for Cz



Conductivity in the z direction is mainly (80%) in the vertical wall of the alveolus.

Conduction through the slab would become significant if the air gaps were a factor 2 or 3 smaller.



Results

This table shows conductivity values (K/W) for the unit cell in three directions.

The first two rows give very simple spreadsheet estimates for the alveolus and slab seperately. The third row is their sum and the fourth is the result of the detailed simulation.

X	Y	Z	
0.136	0.142	0.504	Alveolus only
0.140	0.236	0.137	Slab only
0.276	0.378	0.641	Sum
0.210	0.377	0.687	FlexPDE value

In Y and Z the FlexPDE simulation was not necessary; spreadsheet was good enough. In Z the detailed simulation gives a value between 'alveolus' and 'sum' , as expected.

Assuming that the chip power is 0.1 mW/channel and that the pad size is 5x5 mm^2, then the power per unit cell is P=0.015 W.

We take number of cells in the calorimeter module to be N_x=17, N_x=28 and N_z=40.

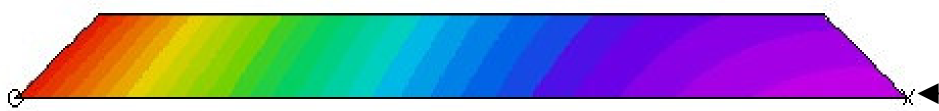
Now making the assumption that the module is a rectangular block cooled in the x direction on just one face we can estimate the temperature difference from

$$\Delta T_x = P\, N_x^2 / (2\, C_x)\ .$$

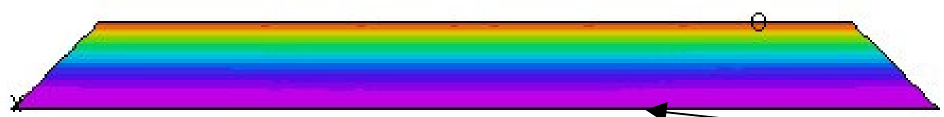
The result is $\Delta T_x = 10.3$, $\Delta T_y = 15.6$, $\Delta T_z = 17.5$

Results 2

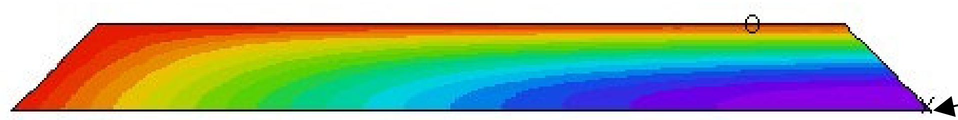
In fact the module is not rectangular and it could be cooled on more than one face, so we use FlexPDE again to solve this problem and find:



Cooling in the Y direction only.
Hottest point is 13.5 degrees



Cooling in the Z direction only.
Hottest face is 19.0 degrees



Cooling in the Y and Z directions.
Hottest point is 10.0 degrees

Conclusions

• The C_y value has little uncertainty because it depends mainly on the dimensions and conductivity of the tungsten, which are both well known. Given the present assumptions about chip power and pad size, it would be possible to cool in the Y direction (along the slabs) with temperature difference of 14 degrees - large but not impossible ?

• The C_z value has huge uncertainty , hardly better than a guess. But if correct it would be not much worse to cool in the Z direction.

• The X direction is presumably unattractive because it would cause a crack in the calorimeter acceptance.

• Combining Y and Z cooling could reduce the temperature difference to 10 degrees.