A Study for Developing a Cryostat for Circuit Testing at Low Temperatures

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Abstract: A simulation study has been performed using COMSOL Multiphysics software for cooling and heating a FR4 PCB and thereafter developing a controller for maintaining the PCB at a fixed temperature for circuit testing at low temperatures. Experimental arrangement was made to cool the PCB and then heating back to room temperature. Experimental results are in reasonably good agreement with simulation curves obtained for cooling and heating the FR4 PCB.

Keywords: Radiation, Conduction, PCB, Liquid Nitrogen, FR4

1. Introduction:

A cryostat has been designed for the circuit testing at low temperatures. The mechanisms are described in such a manner that there is only conduction cooling of the FR4 PCB. However during the heating of the FR4 PCB both conduction and radiation mechanisms are described. As the FR4 PCB is kept inside an evacuated chamber and hence we can consider that the heat loss owing to convection principal is almost negligible. Hence no mechanism for convection has been described.

2. Details of setup for simulation studies:

Arrangement for cooling and heating the FR4 PCB was made by placing a heating element 3 mm above the PCB board with the support of M4 steel screws as shown in Figure 1.

The dimension of the FR4 PCB is given below:-

Width of the block=65mm
Depth of the block=72mm
Height of the block=1.6mm
Thickness of two copper layers =36 micron (double cladded)
Thickness of the FR4 layer= 1.528 mm

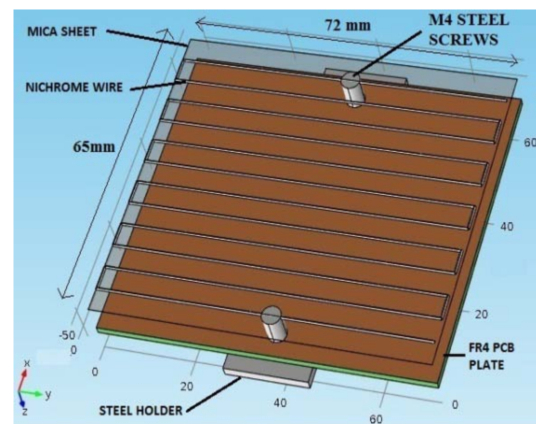

Figure 1. Heating element coupled with FR4 PCB

The heating element was made by winding 12 rounds of a nichrome wire of 20AWG (0.81mm) around a rectangular mica sheet and COMSOL model was done using 12 cylindrical sections with 5 mm gap between each cylindrical section. This section is then united with 11 smaller cylindrical sections.

2.1 Design of Holding Arrangement:

After designing the heating element the holder was designed in COMSOL. For this two blocks of width 15mm, depth 18mm, and height 2mm were taken and placed at the surface of the FR4 PCB for supporting it (supporting blocks) as shown in figure 2. The main source of conduction cooling in the FR4 PCB was through the supporting blocks as they were in direct contact with the PCB. The side rods as shown in figure 2 were of width 5mm, depth 18mm, and height 300mm. The lower support was given by two cylinders of radius 46mm and 49 mm respectively, both are of height 5mm.

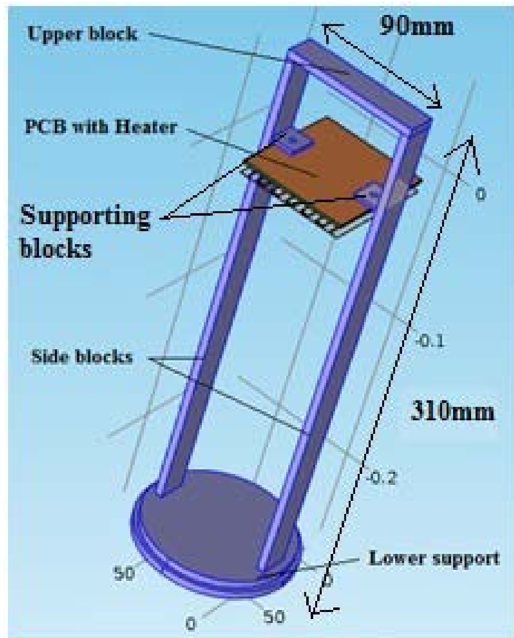

Figure 2. PCB along with holding arrangement

2.2 Design of Evacuated Chamber:

Finally the evacuated chamber was made in COMSOL. The chamber holder as shown in figure 3 is of height 370mm and thickness 7mm. The hollow chamber that has been shown is figure 3 of height 400mm and is of thickness 10mm. The PCB coupled with the heater along with the holding arrangement is kept within thins hollow chamber.

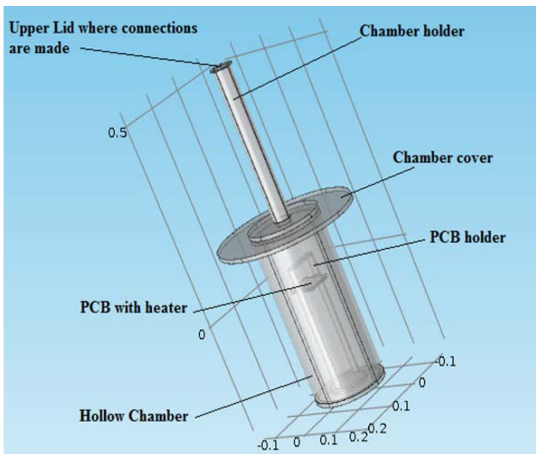

Figure 3. PCB with holder within the evacuated chamber

The heating element along with the FR4 PCB is supported using a holding arrangement made of stainless steel and the schematic diagram of the full setup is shown in Figure 4.

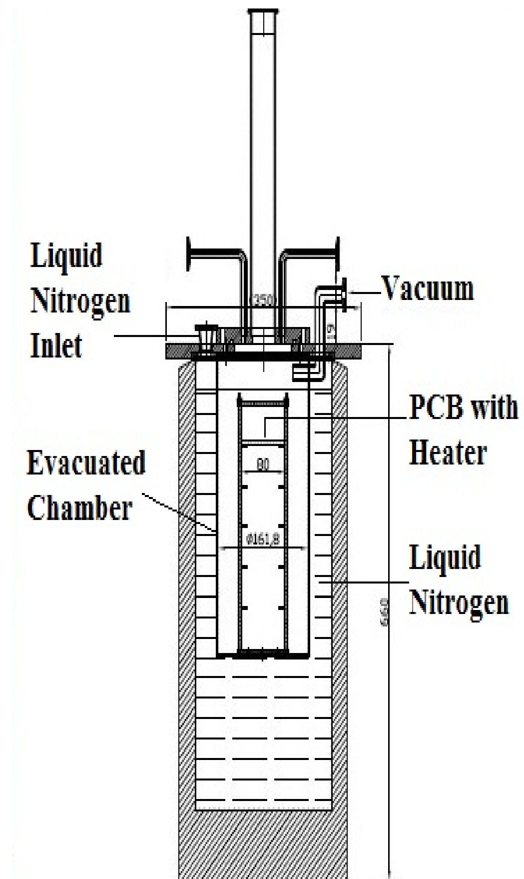

Figure 4. Experimental Setup

2.3 Properties of materials described:

The material properties of FR4, holding fixtures were defined as shown in Table 1.

MATERIALS	Heat capacity at constant pressure(J/KgK)	Density (Kg/m^3)	Default Thermal Conductivity(W/mK)	Surface Emmissivity
FR4	600	1369	0.3	0.66
Copper	385	8700	400	0.78
Nichrome	432	8400	11.3	0.65
Stainless Steel	475	7850	24	0.54
Mica	880	2883	0.71	0.4

Table 1. Material Properties

2.4 Simulation and Study:

In cooling simulation only conduction mechanism was considered while we considered both radiative and conductive processes in heating simulation. In cooling simulation, the initial temperature was set at 300K and the surface of the evacuated chamber that was dipped into liquid nitrogen was set at 77K (the actual temperature of liquid nitrogen). While in the heating simulation the initial value was set at 177K that is the temperature got experimentally after 4 hours of cooling and the heating element (Nichrome wire) as a constant heat source of 20W power is defined under the study of heat transfer. Figure 5, shows temperature distribution on the surface of FR4 PCB at a certain time. A Cut Point 3D was defined at the point as shown in Figure 3, and variation of temperature vs time was studied at this point.

3. Experimental Details:

Experimentally a constant current source of 4A is used to supply the power to the heating element. The variation in voltage as seen from the experimental data collected was from 4.85V to 5.05V. An RTD (Pt100) was placed at the point where the Cut Point 3D was defined. The holder along with the heater was kept into an evacuated chamber as shown in the Figure 4. The chamber containing the heating arrangement was first cooled with the liquid nitrogen and then heated using heating arrangement. The corresponding resistance change of RTD was noted with a multi-meter and the corresponding temperature variation was noted with time.

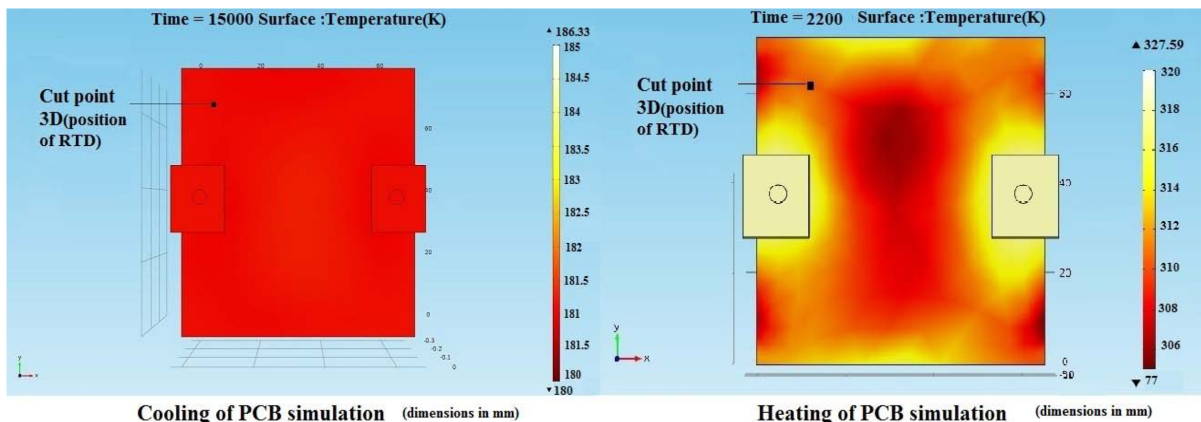

Figure 5. Surface temperature distribution

4. Results:

Plot for temperature variation with time while cooling and heating is shown in Figure 6 where legend 'K' is different thermal conductivity of FR4 material considered in the simulation. We find cooling process slower than simulated result. Studies varying other parameters in the simulation are in progress. While heating also, we find that initially results are in agreement with simulation but temperature achieved is lower than simulated result at a later time.

From 2D simulation, Figure 5 after cooling for 4hours, temperature variation over PCB surface is about 2K. While the temperature variation over the surface is ~ 15 Kelvin after the FR4 as PCB is heated to room temperature.

5. Conclusion

From the cooling curve and the heating curve as shown in figure 6 a few conclusions and observations can be made out.

- It has been found out that the cooling process is a bit slower than the simulated result. Initially the simulated results matches with the experimental results but after a certain span of time it is seen that the cooling process slows down than that speculated by simulation. Hence experimentally a minimum temperature of 177K is got after 4 hours but simulation speculates a minimum temperature of 170K
- While heating also, the initial results are in agreement with the simulation but the temperature achieved is lower than the simulated result at a later time.

However further simulations are in progress by varying other parameters in order to understand the slower heating and cooling rate so that a high quality controller can be designed.

The simulations are in reasonable agreement with the experimental results and further simulation is in progress to understand the slower cooling and heating rate with time so that a high quality controller can be designed.

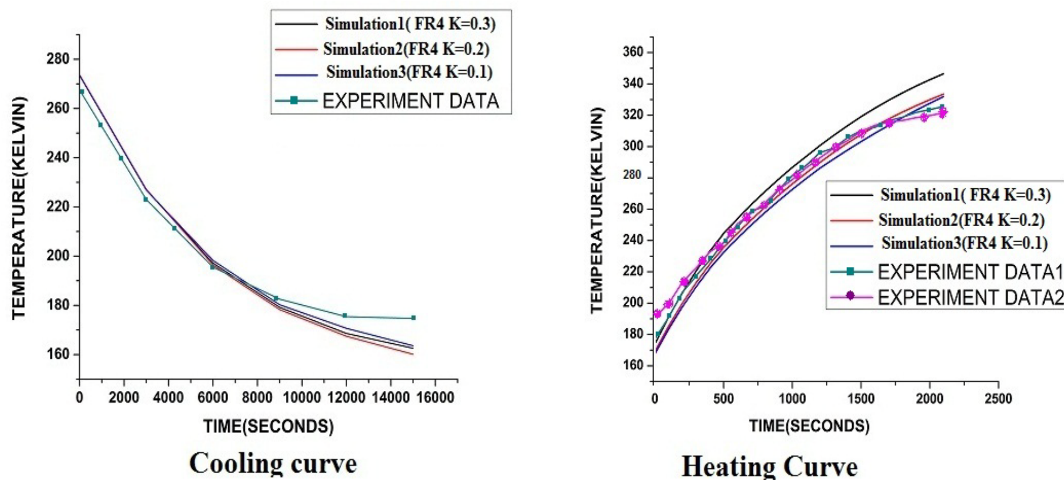

Figure 6. Temperature vs Time plot

6. References

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