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THERMAL BEHAVIOUR OF THE PRESHOWER GALVANIC FEEDTHROUGH

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Abstract

The active components of the read-out planes in the CMS Preshower work at a temperature of about -10°C. An assembled Preshower detector appears as a closed vessel. Electrical services have to cross this container in a gas-tight manner, and they have to be disconnectable from both Preshower outside and inside. To this end, special gas-tight feedthroughs have been designed. As they are located on the cold/warm barrier, their heat inleak can be a potential source of problems. Condensation on the outside surface shall be avoided. This paper presents the behaviour of two different configurations is presented and resulting temperature values at the external surface are compared to the guaranteed maximum dew point temperature.

1 INTRODUCTION

The CMS detector is one of the four particle detectors that will use the LHC accelerator facility to explore the heart of matter, in particular, CMS is optimized for the search of the SM Higgs boson over a mass range from 90 GeV to 1 TeV but it can also study other particle physics at lower luminosities. The Preshower is a sub-detector of CMS designed to enhance $\pi - \gamma^{o}$ separation performance of the electromagnetic calorimeter in the forward region, important in the exploration of the Higgs decay mode H ->$\gamma\gamma$.

Each Preshower detector appears as a wheel perpendicular to the beam axis placed in front of the Endcap Electromagnetic Calorimeter EE. Each wheel contains two circular readout planes made of silicon strips with the associated very front electronics connected by cables and by feedthrough connectors to the outside of the sub-detector. Each readout plane and electronics are thermally protected by two thermal screens placed at either side of the readout plane. The thermal screens are cooled by C_6F_{14} at -10°C. The volume of the wheels is filled with N_2 cooled by the four thermal screens. The wheels' walls are thermally isolated and, between the insulation and the walls, a heated kapton foil keeps the outside wall temperature as required for the neighboring sub-detectors, mainly EE [1].

A feedthrough unit consists of 3 PCBs sandwiched in between aluminium blocks, by adhesive bonding (see Fig. 1). Part of the block's top surface makes direct contact to the SE outer drum. This region is surrounded by an o-ring (neglected in the model), ensuring gas tightness. In order to properly achieve these functions, this top surface is machined after gluing. The PCBs cross from the room temperature level to the cold zone of the preshower. The two extremes of the PCBs' copper traces are joined to pin connector sockets. The pins have been approximated in the model by thin copper links.

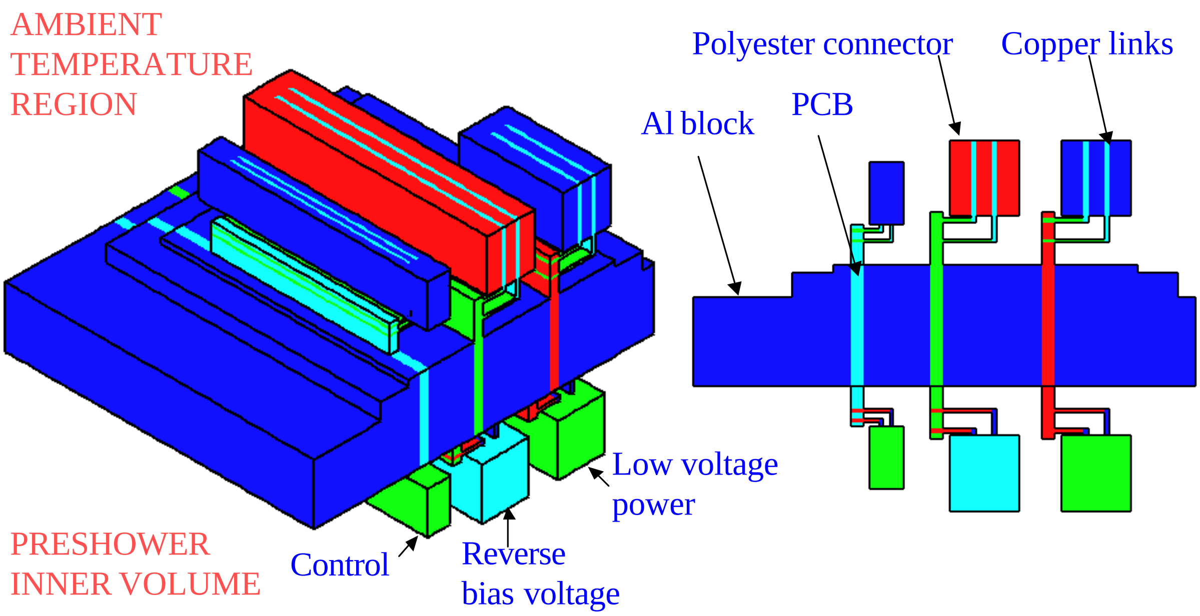

Figure 1 Model of the preshower feedthrough connector, parts and regions. 3D view of half the connector (left) and front view (right)

In the Preshower periphery, only the areas reserved for the feedthrough connectors have no insulation. As the risk of moisture condensation exists on the outside surface of the feedthrough, calculations have been carried out to predict the temperature maps in the region under certain assumptions and case studies.

2 MAIN SIMPLIFICATIONS

A finite element heat-conduction model has been made with four main simplifications:

1. The N_2 influence on the connector's temperature has been input as heat transfer coefficients on the exposed surfaces instead of having simulated the N_2 itself.

The reason behind this assumption is that the cable's bunches modify the space filled with N_2 and perturb in a random manner its movement. Besides, 38 feedthrough connectors are placed around the preshower wheel's outer drum. Each position has different movement of the near-by N_2.

2. The thermal behaviour of the cables inside the Preshower with no electrical current (worst case) was analytically calculated (see Appendix 1).

3. The third simplification considers the external connectors with no external cables connected to be in the worst case scenario.

4. The outer drum was assumed to have constant temperature.

3 BOUNDARY CONDITION AND CASE STUDIES

The boundary conditions applied in the model are:

1. The heat transfer coefficient between the N_2 and the internal exposed surfaces.

2. The heat transfer coefficient between the air and the external exposed surfaces.

3. The heat input through the internal cables.

4. The contact between the outer drum and the feedthrough aluminium block simulated with a constant temperature surface and a thermal contact resistance. (see Fig. 2).

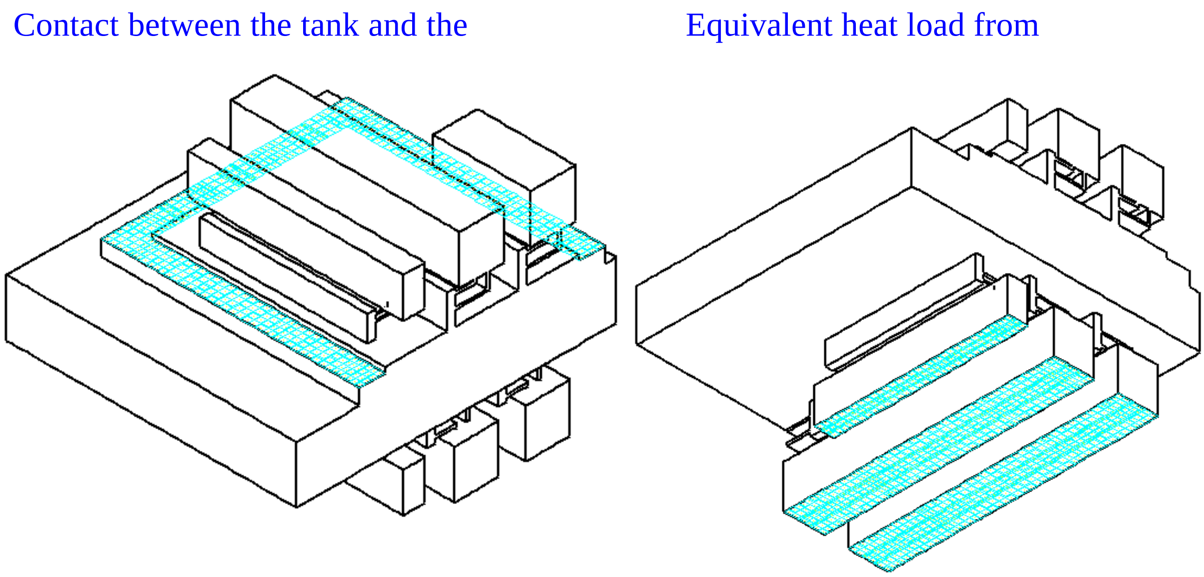

Figure 2 Regions of applications of boundary conditions 3 (right) and 4 (left).

Three different cases have been studied with the use of the commercial Computational Fluid Dynamics (CFD) code Star-CD. In case 1, foreseen values for the heat transfer coefficients (h), thermal contact resistance between the tank and the feedthrough block (R_t) and heat transfer through the cables were considered. In case 2, the heat transfer coefficients inside the preshower and the heat transfer through the cables was multiplied by 10 with respect to case 1. And in case 3, the contact area between the tank and the block of the feedthrough is increased, the temperature inside the preshower (T_{in}) decreased by 10K and the ambient temperature (T_{amb}) decreased by 2K. The T_{amb} - T_{in} varies from 30K in cases 1 and 2 to 38K in case 3.

A summary of the applied boundary conditions for the three different cases analysed is listed in Tables 1 and 2.

Table 1 Parameters for the three studied cases at the ambient temperature region

	h(W/m^{2}K) at ambient temperature level	R_t (m^{2}K /W)	Area of contact between outer drum and feedthrough block (m^2)	T_{amb} (°C)
CASE 1	3	0.00125 (30e-6m of air)	6.88e-4	20

CASE 2	3	0.00125 (30e-6m of air)	6.88e-4	20
CASE 3	3	0.00125 (30e-6m of air)	1.09e-3	18

Table 2 Parameters for the three studied cases inside the preshower

	h(W/m^{2}K) inside the preshower	W/m^{2}K in the control cables	W/m^{2}K in the reverse bias voltage cables	W/m^{2}K in the low voltage cables	T_{in} (°C)
CASE 1	3	42.6	23.5	26.1	-10
CASE 2	30	426	235	261	-10
CASE 3	3	42.6	23.5	26.1	-20

4 RESULTS

Temperature maps for the three studied cases are presented in Figures 3, 4 and 5.

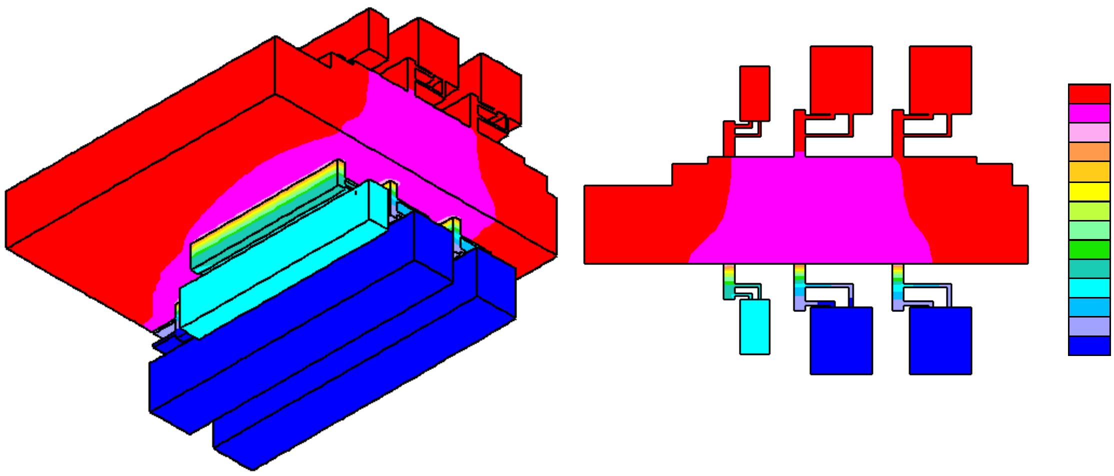

Figure 3 Temperature map for case 1. 3D view (left) and front view (right)

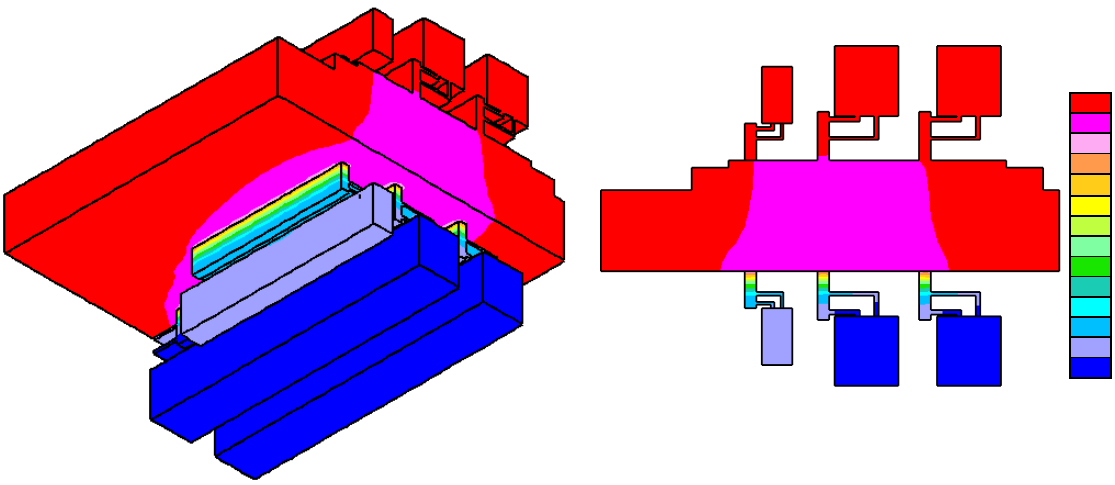

Figure 4 Temperature map for case 2. 3D view (left) and front view (right)

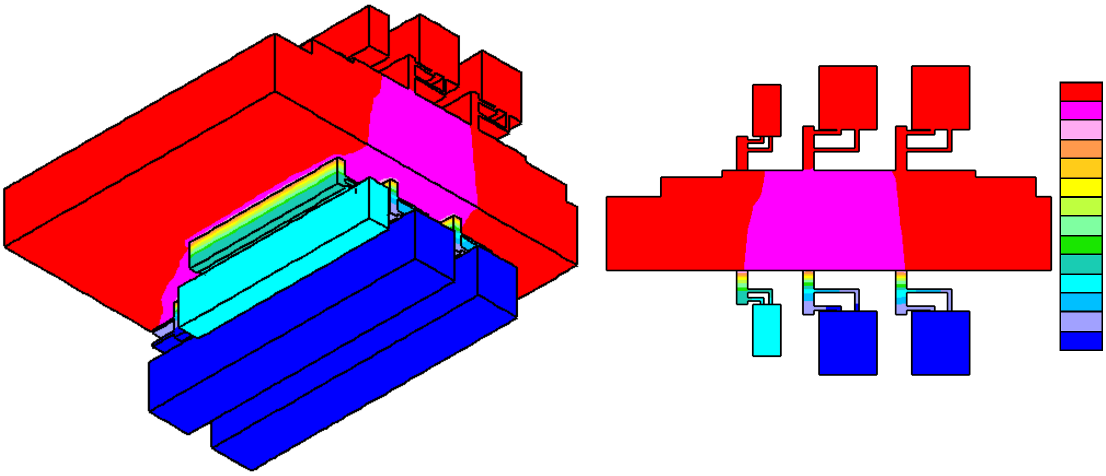

Figure 5 Temperature map for case 3. 3D view (left) and front view (right)

A summary of the results is presented in Table 3. $T_{surfout}$ is the lowest temperature on the outside surface of the feedthrough connector and T_{surfin} is the lowest temperature on the inner surface. A parameter has been calculated in order to ease the comparison in thermal performance among the three studied cases as different boundary temperatures, heat transfer coefficients and contact surface areas have been used for the different cases. It is called Case Characteristic and it is defined as the difference between T_{amb} and $T_{surfout}$ per K of difference between T_{amb} and T_{in}

Table 3 Summary of results for the three studied cases and Case Characteristic

	$T_{surfout}$ (K)	Decrease in $T_{surfout}$ with respect to T_{amb} (K)	T_{surfin} (K)	Increase in T_{surfin} with respect to T_{in} (K)	Case Characteristic: $(T_{amb} - T_{surfout})/(T_{amb} - T_{in})$
Case 1	16.35	3.5	11.15	21.3	0.116
Case 2	10.15	9.7	-4.65	5.5	0.323
Case 3	14.55	3.4	7.85	27.8	0.089

5 CONCLUSIONS

Analysing the results in Table 3, it can be observed that for the realistic cases 1 and 3, $T_{surfout}$ remains above the highest guaranteed dew point temperature set to 12^{o}C and therefore condensation should not take place. It is also important to highlight the effect provoked by the increase in the thermalisation surface. The Case Characteristic passes from 0.116 for case 1 to 0.089 for case 3. In other words, an increase of 58 % in the contact area reduces 30 % the decrease of $T_{surfout}$ with respect T_{amb} and per K of difference between T_{amb} and T_{in}.

REFERENCES

[1] Report submitted in view of the Endcap Electromagnetic Calorimeter Engineering Design Review (ECAL_EDR-04) November 2000 Volume 2: Preshower detector

APPENDIX 1

ANALYTICAL FORMULATION FOR THE ESTIMATION OF THE INNER CABLES' THERMAL EFFECT

In order to simplify the model for the Preshower connector, the thermal behaviour of the inner cables has been calculated separately (courtesy P. Wertelaers) and it is presented in this Appendix.

Fig.6 represents the studied cable. It is connected to a thermal sink (point at which the cable temperature is assumed to be T_∞ for the whole section) and to a connector whose temperature is unknown and equal to Tc

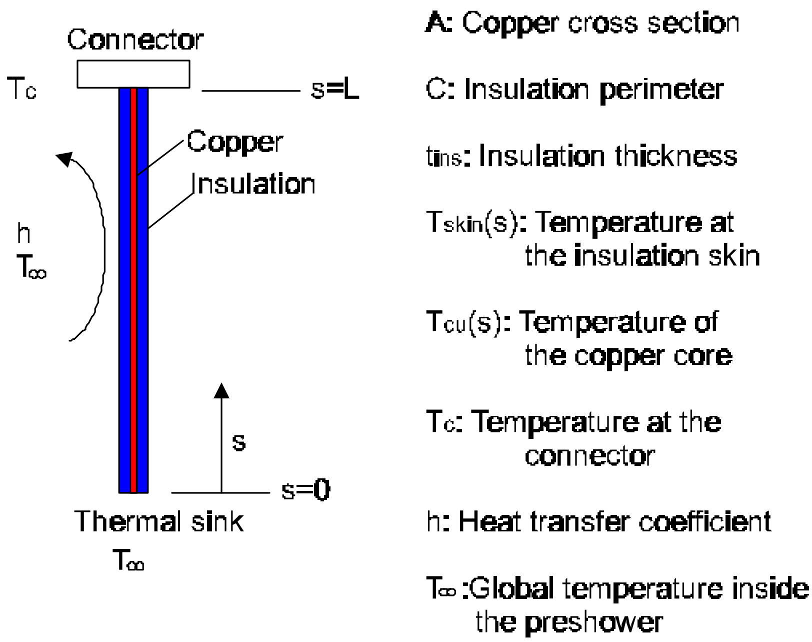

Figure 6 Schematic of an inner cable for the Preshower: parts and thermal parameters

The power dissipated to the N_2 per unit of length in the s direction is given by Eq. 1.

$$P'_t = \frac{dP_t}{ds} = hC(T_{skin}(s) - T_\infty) \qquad (1)$$

Assuming a temperature gradient in the s direction negligible compared to that in the transverse direction, conduction through the insulator is expressed by Eq. 2.

$$P'_t = \frac{dP_t}{ds} = \frac{k_{ins}C}{t_{ins}}(T_{cu}(s) - T_{skin}(s)) \qquad (2)$$

Longitudinal conduction along the Cu gives Eq. 3.

$$P_l = k_{cu}A\frac{dT_{cu}}{ds} \qquad (3)$$

And heat balance in the Cu section produces Eq. 4.

$$\frac{dP_t}{ds} = \frac{dP_l}{ds} \qquad (4)$$

From Eq. 1 and 2, one can solve for Tskin:

$$T_{skin} = \frac{k_{ins}T_{cu} + ht_{ins}T_{\infty}}{k_{ins} + ht_{ins}} \tag{4}$$

Re-writing 2 making use of 3 and 4 gives Eq 5.

$$\frac{d^2T_{cu}}{ds^2} = \beta^2 (T_{cu} - T_{\infty}) \tag{5}$$

Where $\beta^2 = \dfrac{hC}{k_{cu}A(1 + \dfrac{h}{k_{ins}/t_{ins}})}$

As boundary conditions to solve for Tcu, it is assumed that:

$$T_{cu}(0) = T_{\infty} \quad , \; T_{cu}(L) = T_c \quad \text{and} \quad k_{cu}A\frac{dT_{cu}}{ds}(L) = P_c \tag{6}$$

From 5, it is obtained that Tcu(s) has the following solution:

$$T_{cu}(s) = B\sinh \beta s + D\cosh \beta s + T_{\infty} \tag{7}$$

Applying the boundary conditions mentioned in 6, it is obtained that the power reaching the connector is as given in Eq. 8.

$$P_c = \mathrm{K}(T_c - T_{\infty}) \tag{8}$$

Where $\mathrm{K} = \dfrac{k_{cu}A\beta}{\tanh \beta L}$ (9)

APPLICATION TO THE CABLING INSIDE THE PRESHOWER

As the air distribution around the cables will be hindered by the neighbouring cables, the expected heat transfer coefficient with the N_2 is very low. For conservative reasons, the assumed h is 1 W/m^{2}K. Table A1 presents the cables' external diameter, their copper section, insulation thickness, the amount of cables per connector and the connector surface together with the resulting K.

Table A1 Parameters of cables and connectors inside the Preshower

	Dext (mm)	Cu section (mm^2)	Insulation thickness (mm)	Amount per connector	Connector surface (mm^2)	K (W/m^2K)
Control cables	0.6	0.057	0.175	34	173	42.6
Reverse bias voltage cables	0.8	0.09	0.21	36	492	13.5
Low voltage cables	0.8	0.09	0.21	40	492	26.1