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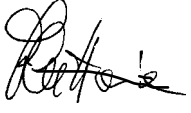
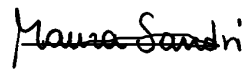
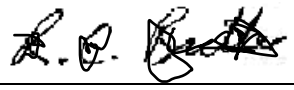
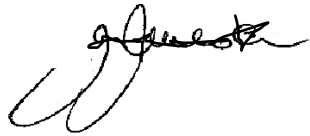


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 INVESTIGATION AFTER SENSORS
 FAILURE

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1 DEFINITION OF THE PROBLEM

During RAA FM tests, several doubtful behaviours have been observed, related both to the Thermal and Radiometric characterization of the SKY LOAD (SKL).

In particular, they can be summarized as follows:

- very large thermal offset between the sensor on the metal plate backing the SKL (named SKL1 and 2, following the LAMA nomenclature) and the sensor put on a central pyramid (ECCOSORB) of the SKL.
- strange behaviour of the sensor put on the ECCOSORB panel side: its offset with respect to the SKL1/2 changes largely from COLD to HOT state, beginning also negative above a certain soil (TBD).
- Noise temperatures much lower than expected. Values found at RAA level (basing on sensors put on the ECCOSORB) are very far from RCA results and, for several channels that are believed to not work properly, should be considered at least unrealistic.

It was required from the Scientific Team to attempt a first level analysis in order to give an estimation of uncertainty tied with :

Expected temperatures read from sensors

Expected temperature 'seen' from the radiometers.

The output of this work should provide an answer about the possibility of using the sensor SKL1/2 as input to perform the analysis of RAA radiometric properties, in the case of effective failure of the ECCOSORB sensors.

An accurate analysis can not be performed in a few days but requires more accurate investigations: because of that, it will be provided here an estimation of the expected uncertainty on temperature observed from the feedhorn when the SKL1/2 sensor only are used.

The global analysis foresees the matching between a Thermal and Radiometric investigation: the two models will be here presented firstly separately and results will be at the end related in order to fix a uncertainty in Detectors properties. Models bases either on computational analysis and experimental results.

The document flow will be:

- Design definition
- Thermal Model
- Radiometric Model
- Mix of the two models and impact on Detectors properties.
- Conclusions



2 DESIGN:

The sky load is a polygonal absorber positioned in front of the FPU, with the center coaxial with the FPU and 190 (D1) mm far from it.

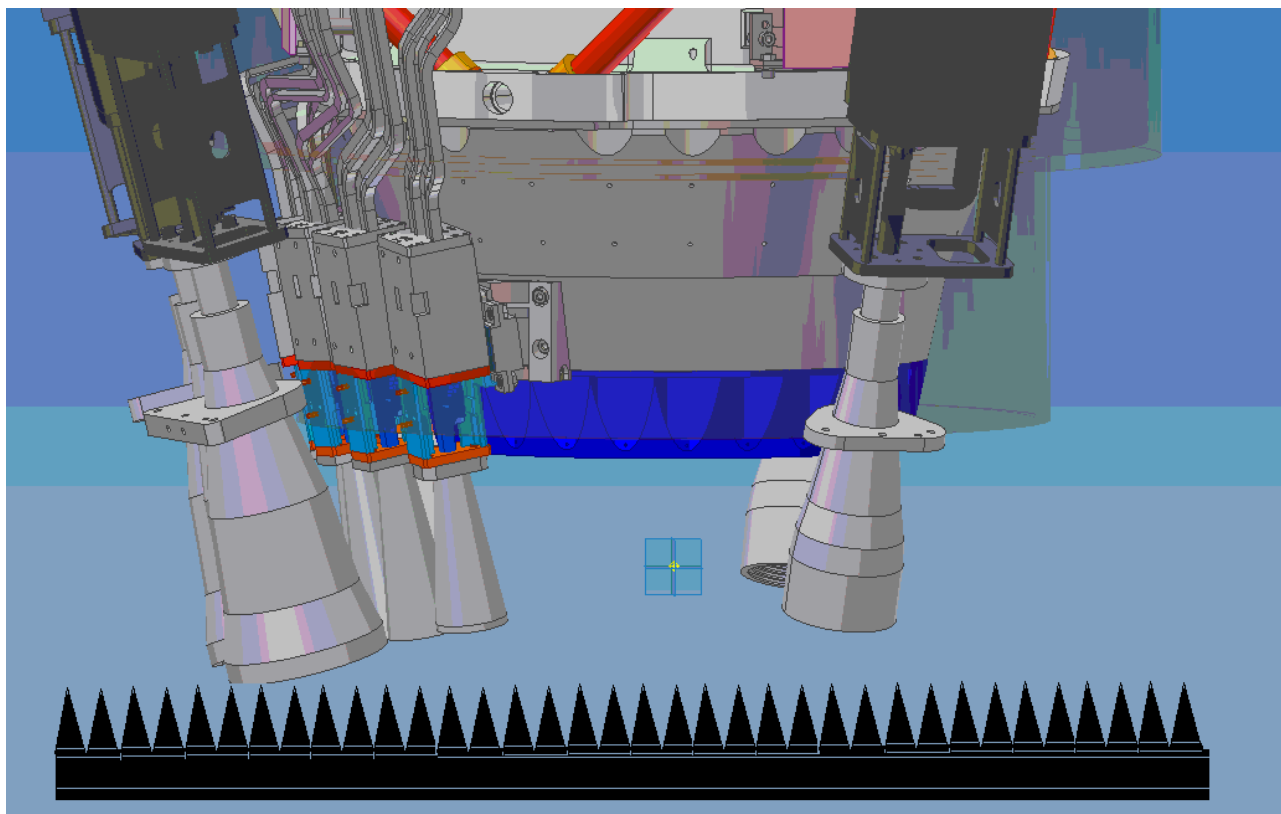


Figure 1 SKL positioning in front of the LFI FPU

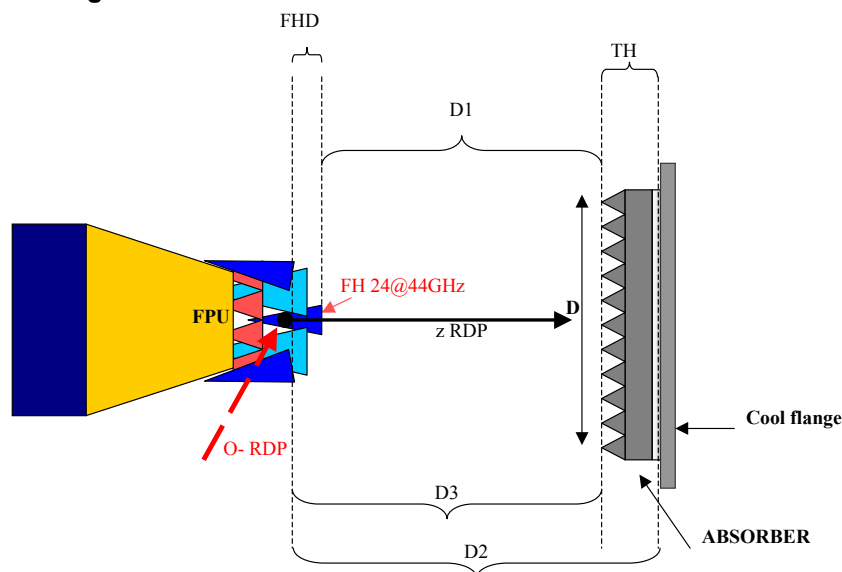


Figure 2

The absorber is modular: the final design is obtained joining many panels. Each panel is a bed of pyramids, each one having side 5 mm and height 30 mm. Each pyramid is backed



by a box 5X5X10 mm. Panels are screwed to a single metal panel (aluminium) and can float on it in order to compensate for differential thermal contraction.. Panels have a very weak lateral contact: in this sense, each panel can be analysed as an independent part.

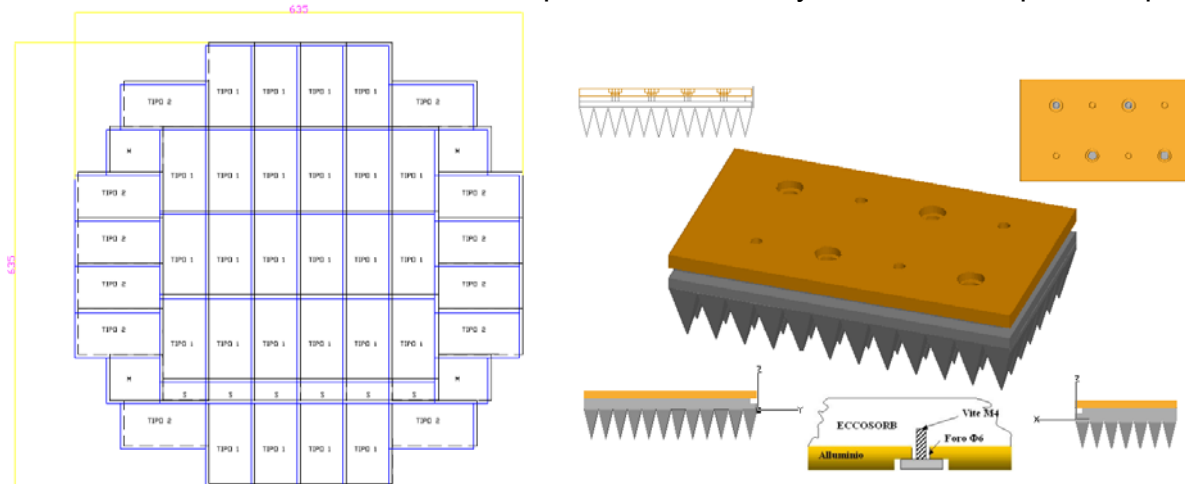


Figure 3 left panel: SKL assembly; right panel: single unit module.

The SKL operates inside a complex thermal environment: it looks, for most of its surface, directly toward the FPU (about 20K) and the MAIN FRAME (about 25 K): the normal projection of these two objects on the SKL intercepts the larger part of the SKL. The lateral environment is instead represented from parts of the LFI and of the cryofacility staying at an average (computed on all parts) temperature of about 58 K.

3 THERMAL MODEL

An experiment has been set in IASF-BO in order to characterize a single panel and to reproduce a situation in some way representative of the LABEN RAA setup. After that, the analytic model trying to reproduce the laboratory measurement and the RAA setup will be presented.

3.1 Experimental setup

A pyramid panel representative of the sky load, is mounted in the cryofacility.

It is screwed to an Aluminum base where a heater and a thermometer (sensor B) are mounted for the temperature control. Four sensors (G0 to G3) are mounted on the Eccosorb structure. One is screwed on the base and others are mounted on the pyramid tips (two lateral with a larger radiative load and one on a central pyramid), as shown in **Errore. L'origine riferimento non è stata trovata..**

All sensor locations are summarized in Table 1

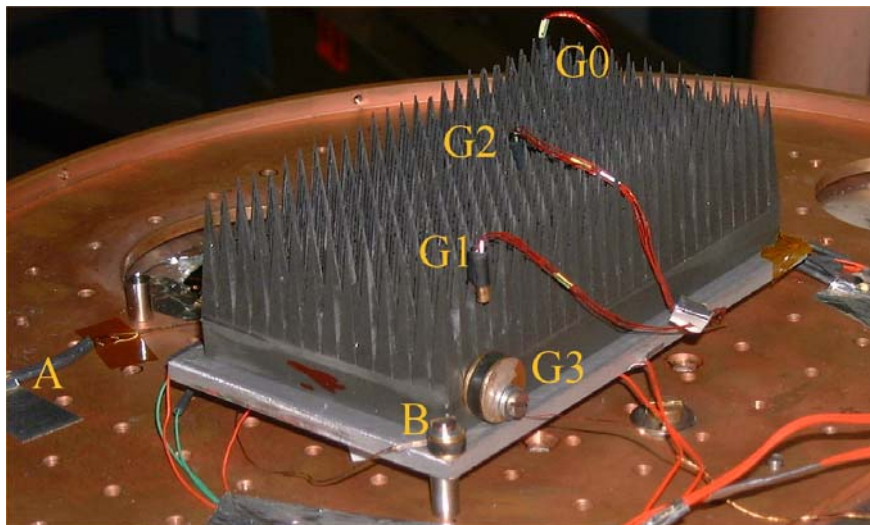


Figure 4 Temperature sensors location on the Eccosorb panel (G0-G3), the Al control flange (B) and the cooler cold flange (A).

An external copper shield (**Errore. L'origine riferimento non è stata trovata.**) is then mounted around the sample in order to provide an isothermal radiative environment. The inner surface is covered by means of a black plastic tape in order to increase the shield emissivity.

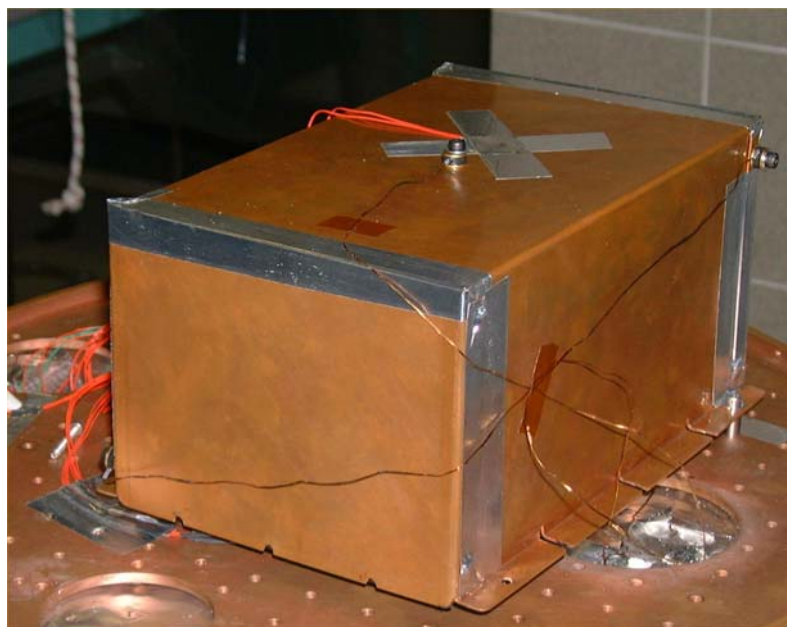


Figure 5 Radiative shield. The copper inside is blackened. On the top the sensor and heater for temperature control are visible; on the right one of the other sensors monitoring the shield temperature.



Sensor ID	Type	Location
G0	GR200	Corner pyramid
G1	GR200	Lateral pyramid over G3
G2	GR200	Central pyramid
G3	GR200	Eccosorb base
A	DT670	Cold flange
B	CX1050	Al support
S1	DT670	Copper shield (bottom corner)
S2	DT670	Copper shield (on top, close to heater)
S3	DT670	Copper shield (top corner)

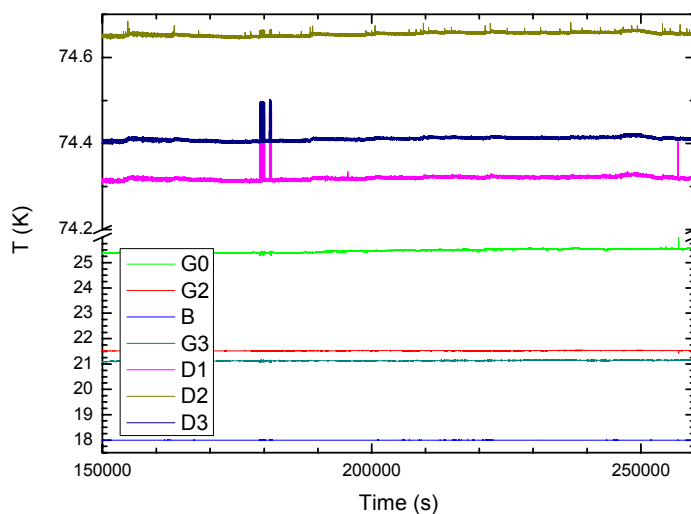
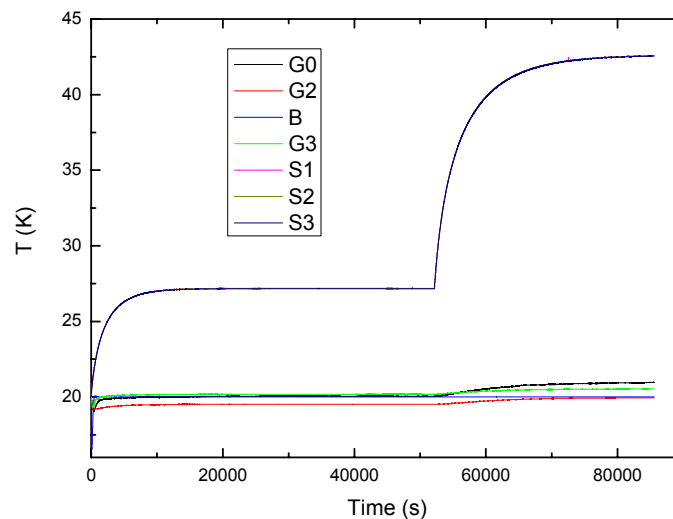
Table 1 Sensor type and location.

3.2 Test results

After the thermalization of the system at the minimum temperature, below 3 K, the two control stages were put to 20 K. The central pyramid sensor (G2) has an offset of about 0.55 K in the measurement due to parasitic load from the wires.

Panel control T (K)	Shield control T (K)	G3	G0	G2
20.0	20.03	20.085	19.88	19.435
20.0	27.17	20.166	20.04	19.51
20.0	42.575	20.529	20.959	19.932
20.0	81.853	23.515	29.038	24.573
18.0	74.654	21.147	25.559	21.527

Table 2 Summary of steady state data measured at different controlled temperatures.



Our setup can be considered a worst case radiative load with respect to the RAA chamber sky load, where the central pyramids, seen by the feed horns have the 25 K stage on the axis direction.

3.3 Model

We used these measurement data to develop a thermal model that could give an estimate of the RAA sky load temperature observed by the LFI radiometers. In **Table 3**, results of the simulations are shown with the different radiative environment than what measured. An accuracy of about 1 K was recovered.



Panel control T (K)	Shield control T (K)	G3	G2
20.0	42.58	20.22	20.37
20.0	81.85	23.23	25.32
18.0	74.65	20.26	21.72

Table 3 Summary of model results with the same boundary conditions of measurements.

In **Table 4** model results with a radiative environment of 60 K (approximately the average value of thermal tent sensors measured in the RAA FM tests)

Sky control T (K)	Shroud T (K)	Sky side	Central pyramid
18.0	60.0	18.93	19.53
25.0	60.0	25.91	26.49
30.0	60.0	30.87	31.44
35.0	60.0	35.82	36.35

Table 4 Summary of model results with different sky control temperatures.

The temperature offset between sky control backplate and the pyramid is decreasing of about 200 mK when the backplate is changing between 18 and 35 K.

This analysis is intended as preliminary because uncertainties and approximations in the model need further investigations.

4 RADIOMETRIC MODEL

The system FPU + SKL has been modelled from a Radiometric point of view in order to have a first rough estimation of the uncertainty related with the antenna temperature observed from the feedhorns.

Model takes into account:

- The material (ECCOSORB) properties, permittivity and tangent loss.
- The shape of the load.
- The positioning of the load with respect on the FPU.
- The dependence on frequency.
- The real properties of the feedhorns (coordinate system with respect to the FPU and near field patterns)

Modelling arises from a combination of several techniques using: Finite Elements Method (HFSS-Ansoft) to investigate the panel effective emissivity and Spillover, Geometric Optics (GRASP) to evaluate the near field properties of the LFI feeds, analytic computation ('Air fractional model') to investigate the 'equivalent temperature' of the load, laboratory measurements to evaluate electric parameters of the absorbing material and to check the panel reflectivity.



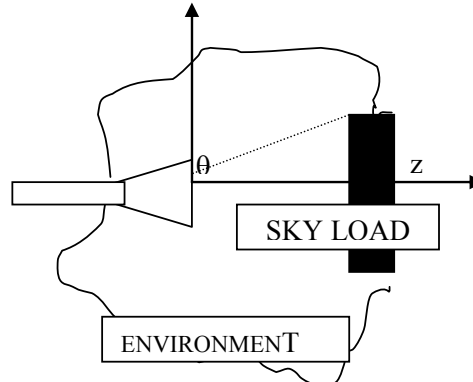
4.1 The modeling flow

It can be summarized as follows:

- Calculate the near field pattern for each feed and represent it on a grid, having the same dimensions of the load and put 190 mm far from the nearest feed aperture.
- Match all near field contour plots in order to define the envelope of the region mostly watched from the feeds.
- Calculate the SKL intrinsic reflectivity and Spillover in order to calculate its total emissivity (inputs for the model are based on measurements performed by IASF-Bo& IFP-Mi in 2003 and on analytic calculation based on data from literature)
- Divide each pyramid in sections of equal height and calculate the contribution to the total emissivity given from each layer.
- Convolve the purely RF results with those from the thermal model in order to get a combined RF-THERMAL model giving account of the global radiometric properties.

4.2 THE MODEL

Known the angular *power pattern distribution* $P(\theta)$ of the feed and the intrinsic reflectivity R at each frequency, it is then fundamental relating the two characteristics above with the physical temperature, $T(\theta)$ to describe the environment seen by the feed in terms of a single parameter, which we define as *normalised equivalent temperature*. Taking the origin of our reference system coincident with the center of the feed mouth, as a first step we can reduce the problem to a two dimensional representation in the plane $\square[xz]$, where the x axis lies on the aperture plane and the z axis coincides with the feed horn axis.



We define *effective emissivity pattern* $P_{\square}(\square)$ the convolution product of the *power pattern distribution* with the angular emissivity pattern.

$$P_{\varepsilon}(\vartheta) = \int_0^{\pi} P_{\nu}(\vartheta) \varepsilon(\theta) d\vartheta$$

In this frame, the *normalized equivalent temperature* (since the emissivity pattern is normalized to the total power emitted by the feed horn) can be defined as the convolution product of the *effective emissivity pattern* with the temperature angular distribution. Both the quantities can be expressed in function of the angle θ between the z axis and the vector joining the origin with the middle point of the considered section, or, in equivalent way, into Cartesian coordinates projected on the SKL surface.



So, the entire structure reduces to a discrete succession of elements, each one characterized by a constant (at a specific time) temperature, by its effective emissivity (depending on the emitting surface subtended by that angle) and the angle θ subtended.

At this first level, near field patterns have been used **only to individuate the maximum region effectively looked from the feedhorns**, at least within a reasonable level of power.

Near field contour plots have been calculated and projected on the SKL surface. The envelope of contour plots indicates an asymmetric region of the SKL mostly contributing to the global emissivity with $\varepsilon > 0.995$

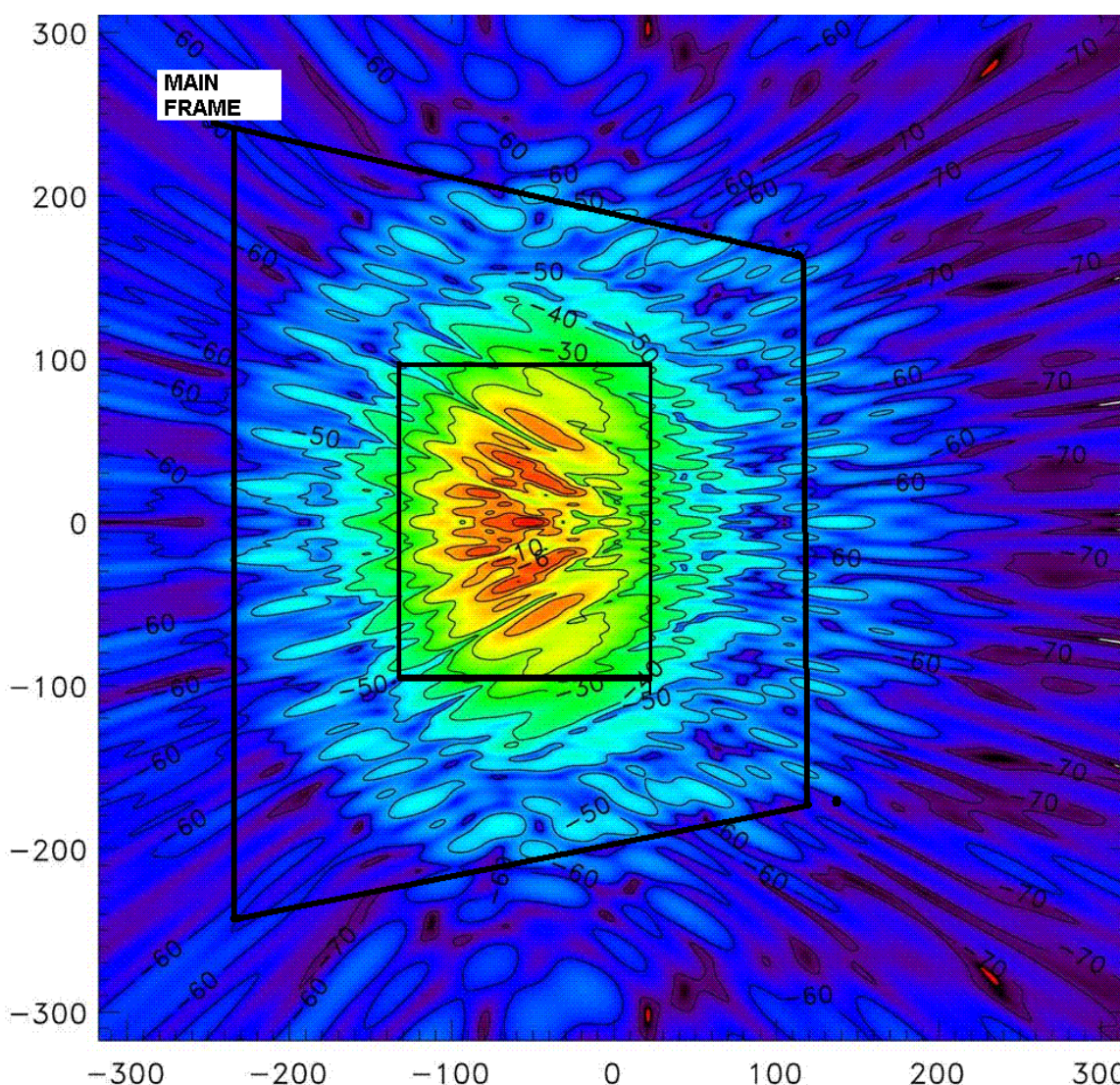


Figure 6 total envelope of the contour plots due to each channel: X and Y coordinates are representative of the SKL overall dimensions. The inner rectangle indicates the region with normalized power emitted > 0.99 ; the trapezoid indicates the orthogonal projection of the Main frame (region with T around 25 K) on the SKL surface.



The contour plots show that the 'active' region of the SKL is embedded in a smaller area directly observing the FPU and the Main frame.

The emissivity of each panel was evaluated by model using FEM methods and measured in IASF-Bo through S-parameters measurements on a single panel. In both cases, results indicated for a single panel ϵ larger than 0.999.

The Spillover (SPO, direct and indirect, i.e directly entering the feeds or after a reflection on the SKL surface) was only modeled: results set a limit to radiation incoming from the environment below 0.00015

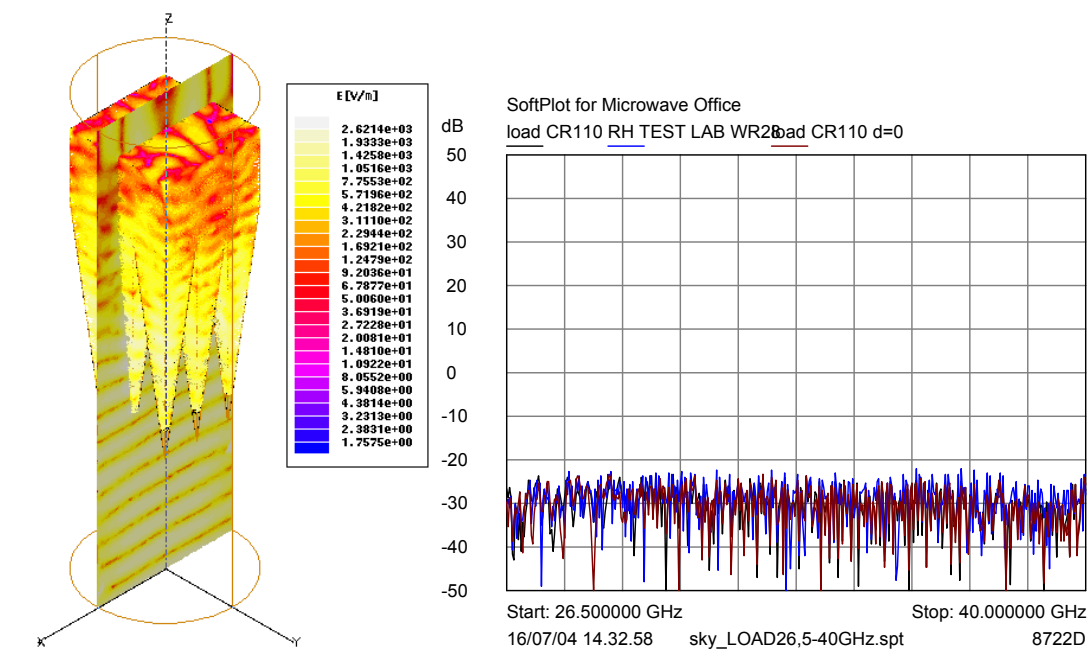


Fig. 1 left panel: E-Field distribution inside a representative bed of pyramids with several dulled tips. The colour scale is logarithmic ; right panel: results from SNA measurement between 26 and 40 GHz: the total reflectivity is represented, for a panel put in front of a laboratory feed in the worst case condition (distance horn-load = 0 mm). As it is clear, reflectivity is dominated from the test horn properties (blue trace)

An analytic model was also been implemented to evaluate the contribution given to the total emissivity from each pyramid: it allows to parameterize the thermal distribution along the Z axis (height) of each pyramid .

Pyramids have been decomposed into 5 layers, plus one due to the ECCOSORB back block (10 mm thick).

Calculation bases on 'air fractional model', computing the RF transmitted and reflected components in each layer: it allows to evaluate the 'equivalent antenna temperature', that is the temperature effectively watched from the feedhorns when a thermal gradient is applied along the pyramid. Results are shown in the diagram below.

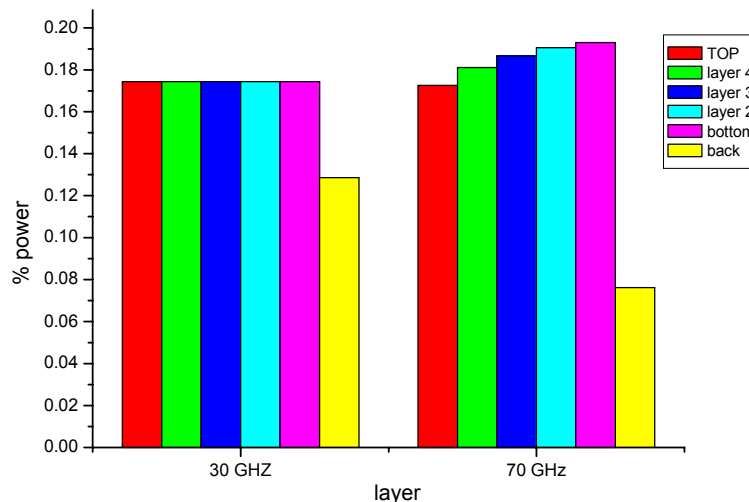


Figure 7 contribution given from each discrete layer to the total emissivity of a pyramid. Final result is only weakly dependent on frequency. Values will be convolved with the expected temperature gradient along the pyramid.

4.3 MAIN RESULTS

From radiometric modelling, we can conclude that:

- Each panel has emissivity very close to 1 ($\epsilon > 0.999$)
- The Spillover (SPO) component is about $1E-4$ of the normalized power reaching each feed (it means that only .0001 of the power emitted from higher temperature regions reaches the feeds. If the warmest surrounding is supposed to have temperature of about 60K, it means a thermal excess of less than 0.1K.
- Emission properties are about independent on the channel (frequency).
- Feeds watch a narrow region with respect on the total surface of the SKL. This feature has two main advantages:

- Panels subjected on the thermal radiation from the warmest regions of the surrounding have marginal importance (close to be negligible)

- The radial thermal gradient (due to different radiative situations of the panels) observed from a central feed (70 GHz, for example) respect to a lateral feed (30 GHz for example) is really small since the maximum radiative power on the SKL is here due to the FPU and Main Frame.

- it is possible, given the expected thermal gradient along the pyramid, to define an equivalent temperature representing the integrated power load observed from each feed.



5 GLOBAL MODEL

Results from Thermal and Radiometric analysis can be synthesised in order to get an estimation of the real impact of thermal uncertainties, due to the supposed failure of some sensors, on detectors performances.

The thermal model has still a possible uncertainty due to the procedure followed to define the radiative boundaries: however, as it is reported below, if it would be confirmed it should not sensibly impact on final result.

Uncertainties due to the specific quantities entering the full analysis are reported hereafter.

a) Absolute thermal offset (A) between the metal plate backing SKL and the Eccosorb block 10mm thick backing pyramids

→ at present we do not still know if the Thermal model hides an error avoiding to define precisely this term; if it does exist, however, it can operate only as a constant to be added in the same way both to the HOT and to the LOW temperatures evaluated for the ECCOSORB side sensor. Uncertainty due to this term can be quantified here $< 2K$.

b) OFFSET (O) between sky control backplate (SKL1) and the pyramid: it is estimated to decrease with $T(SKL1)$ by 200 mK over 17 K increment .

→ Uncertainty possibly due to this term is estimated in 300 mK . It varies following the same linear trend of the OFFSET itself. At the end it must also be multiplied by the equivalent radiometric temperature factor (that is about 0.7); so uncertainty decreases to 200 mK about

c) radial gradient (R) from central pyramid to side pyramid:

→ results from radiometric model avoid that any lateral pyramid is observed from the feeds: from B section of thermal modelling, a difference of 2K can be related to this term in the worst case conditions (corner pyramid versus central pyramid): however, here the field of view never allows an observed pyramid to behaves as corner pyramid. Moreover, the feed horn beam is not a pencil beam looking only a few pyramids, so the net power is the average over many pyramids: this is why this effect is expected to be very smooth in the actual setup and to have, at the first order, a negligible impact. However, an attempt to give an estimation of this effect has been done considering a gradient varying linearly from the region subtending the main frame and the center of the focal plane. This variation has been then convolved with a typical 70 GHz beam, in order to maximize the effect (70 GHz feeds have the narrowest beam size).

It results in a further offset between 0.3 and 0.6K , depending on the position of the feed. This offset keeps about constant from hot to cold state.

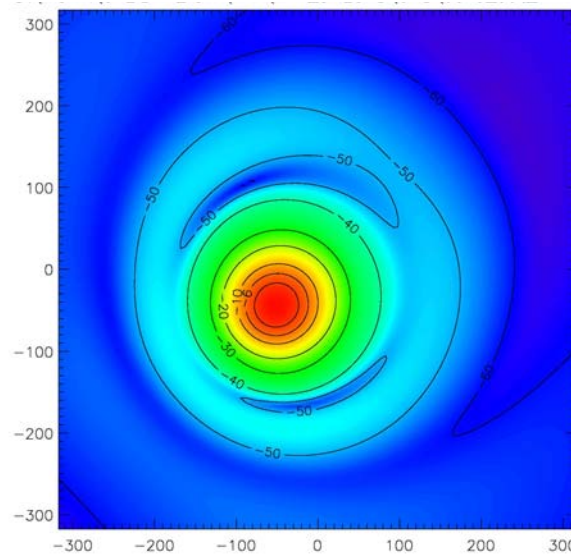


Figure 8 Feed horn 18: contour plot projection on SKL surface. The most power (>0.99) is located in a region with diameter $d < 150\text{mm}$. Other feeds have similar behaviours or, at least, comparable.

c) SKL emissivity ε : it was estimated in the worst case to be >0.999

→ this term has been evaluated by model and experimentally: it could be also higher; it has not any impact; result can only improve.

d) uncertainties tied to near field contour plot definition, and to the air fractional model:

→ at this level can not have any impact.

Given the metal plate temperature SKL1, the physical temperature observed by the feeds is then:

$$T = T_{SKL1} + T_{SPO} + \left[A|_0^{+2} + \Delta|_0^{0.3} + O(T) + R(d) \right] \cdot \mathfrak{Z}$$

Where:

A = offset metal plate – ECCOSORB base

Δ = difference between the tip of the pyramid and the eccosorb base

$O(T) = \left(\frac{2|_0^{+0.3}}{170} \right) \cdot (18 - T_{SKL})$ is the variation of the term A with T: it acts in an asymmetric way in the hot and cold state.

$R(d) = \left(1 - \frac{d_1}{d_2} \right) \cdot \int_{BEAM} T(d|_0^{150})$ is the thermal radial gradient along the SKL, weighted by the beam size, considering the position of the beam, and convolved with the normalized power of the feed.



This calculation has been applied to simulated data: Noise temperature has been calculated both using metal back plate (SKL1) sensor and temperatures derived from it following the method described above.

Uncertainties have been applied to the parameters and they have been run in all combinations, to estimate the maximum deviation respect to the result obtained from having used SKL1.

Comparison is reported in the following column plot, displaying also the error bars due to uncertainties of the model.

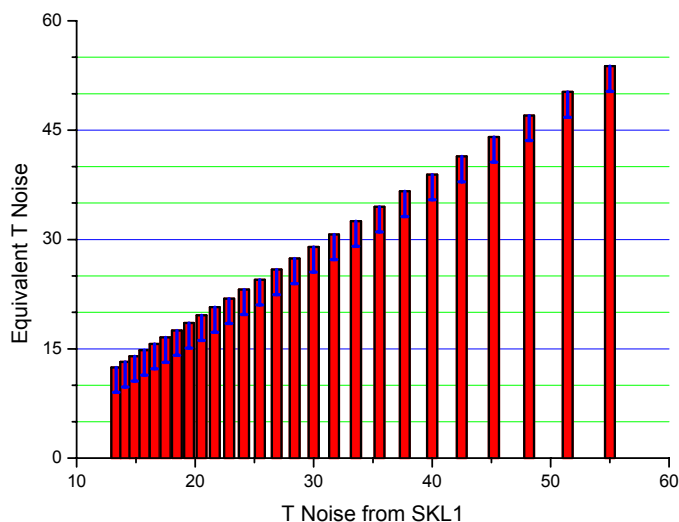


Figure 9 Noise temperature from model versus estimated from SKL1; model error bars are displayed

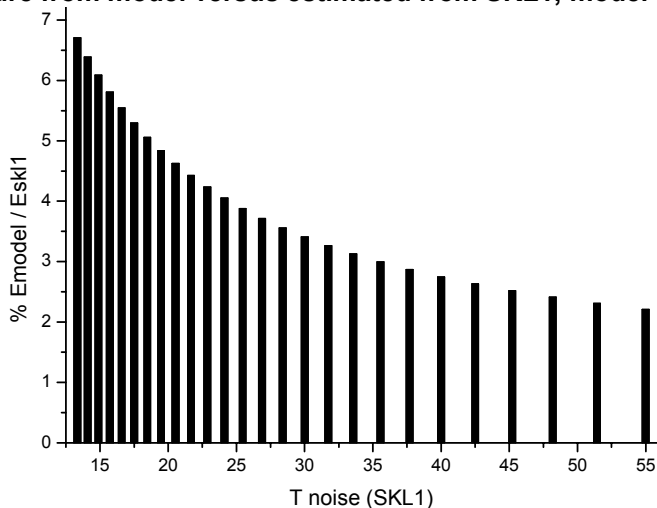


Figure 10 Percent difference between SKL1 and Model (nominal) results: data are plotted vs noise temperature. Error reduces when Noise Temperature increases.

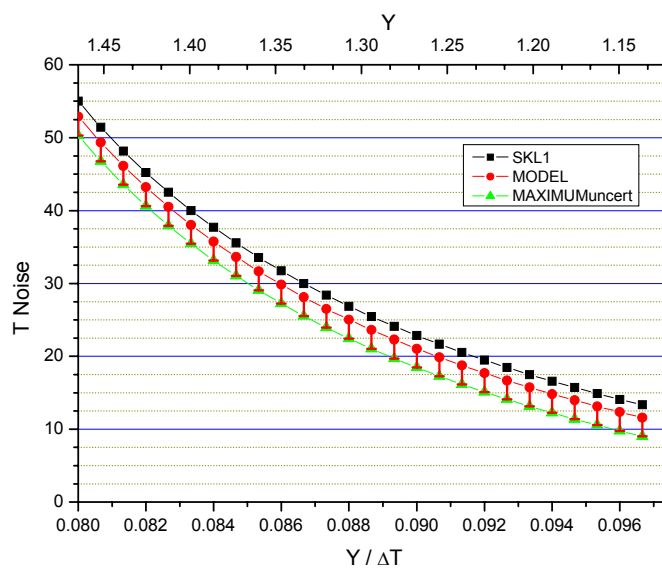


Figure 11 noise temperatures obtained from SKL1 (black) and from Model (red) represented versus Y factor and normalized $Y/\Delta T$. Error bars related to the model are displayed: the green curve is the limit of uncertainty envelop.



6 CONCLUSIONS

RAA calibration tests require a good knowledge of the sky load temperature. Three thermal sensors have been positioned, by design, in three different regions of the SKL: on the metal plate backing the absorber (SKL1), on the tip of a central pyramid and on side of the absorbing plate 10 mm thick backing pyramids. The last two seem to have undergone a failure, probably due to independent causes: sensor on pyramid shows a poor thermal contact while the side sensor seems to be probably affected by a conductive entrance, diversely weighting on Hot and Cold states.

This document try to answer the need of understanding if it is possible to get reasonable results using just the back plate sensor and, if that is true, to estimate the related uncertainty.

This task required that a thermal and a radiometric model of the system were implemented. The two models have been treated separately and, at last, matched together in order to provide an harmonized result.

Models base both on computational techniques and on experimental dedicated measurements: although they have still several dark points to be investigated, mostly due to the short time available for the analysis, however are able to provide an estimation of the real temperature seen from the feeds, and of the uncertainty in Noise Temperature evaluation when just the metal plate sensor is used.

Results indicate that the sensor SKL1, put on metal plate, is, within a reasonable uncertainty, representative of the Load temperature seen from the feeds. Noise temperatures evaluated using SKL1 come out always higher than expected by less than 2 K; expected results can still hide a systematic, due to the definition used to represent a radiative boundary; this lack makes the uncertainty increase by about 2 K, growing inversely proportional to the absolute noise temperature. This uncertainty will be hopefully removed in the next issue of this document.

However, since noise temperature calculated using SKL1 is always higher than the expected real value, it can anyway be considered as a worst case, within the uncertainties lined in this document.