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Pulsed carbon fiber illuminators for FIR instrument characterization

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ABSTRACT

This article describes the properties of the carbon fibers that were used during the ground calibration of the High Frequency Instrument of the Planck satellite. It focuses on the properties of this new device used as radiation sources, and on the modelling of its thermal behaviour. Experimental data are presented and successfully compared with the proposed theory. Their small time constant, their stability and their emission spectrum pointing in the submm range make these fibers a very useful tool for characterizing FIR instruments.

1. Introduction

We have been studying carbon fibers as illuminators for FIR instrument characterization between 2000 and 2005 with the specific goal of measuring the sum of the electrical and optical crosstalk between the different channels of the High Frequency Instrument of the Planck satellite [1,2].

As far as this article is concerned, most of the effort has been put on thermal modelling since a good agreement has been obtained between data and simulations within this framework. The first section gives an overall view of the experimental setup and ends up with a list of requirements for the carbon fibers. The second section details the fiber device and its electronics. While the third and fourth sections give the basic equations used to determine the fibers behaviour and the extraction from experimental data of their main properties, ending up with a self consistent comparison with simulations.

2. Experimental setup

2.1. Planck-HFI

The ESA CMB Planck mission will be launched in April 2009. It will produce full sky maps in nine frequency bands ranging from 30 to 1000 GHz, including polarisation maps up to 350 GHz. The full analysis of these maps will provide percent level constraints on cosmological models. The satellite hosts a 1.5 m diameter telescope that sweeps slowly the sky. Two instruments share the focal plane: The Low Frequency Instrument (LFI), up to 100 GHz, uses HEMT as detectors, and the High Frequency Instrument (HFI), based on bolometers, covers frequencies from 100 to 1000 GHz. This work has been motivated by specific needs of HFI bolometers ground calibration.

2.2. The Saturn setup

HFI bolometers working point is around 100 mK. On the satellite, a three stages cryogenic system provides a very stable thermal environment, required by the exceptional instrument sensitivity. For ground testing and calibration at the instrument level, a specific environment has been developed at IAS Orsay, with similar requirements. This so-called "Saturn" cryostat, where HFI ground calibrations took place, allowed us also to lead the thermal characterization of the source fibers during the cooling down of the setup, for temperature ranging from 300 K to 1.7 K.

Inside the cryostat, a 2 K enclosure contains the HFI Instrument and the calibration optical system detailed in [3]: an integrating sphere fed by internal sources and a path to external sources, a spherical mirror conjugating the output of the sphere and the HFI focal plane, and an instrumented support. This 2 K enclosure is surrounded by a 20 K and a 80 K shield.

The fibers setup is installed on the instrumented support, on a side of a three position wheel. The light sources are facing the entrance of part of the cold optics of the instrument, as shown on Fig. 1. Two additional fibers are installed behind a dedicated small hole in the mirror facing the focal plane. They illuminate all the bolometers synchronously for time constant measurements purposes. Being further from the instrument, the mirror fibers illuminate the HFI horns about 300 times less than the wheel fibers.

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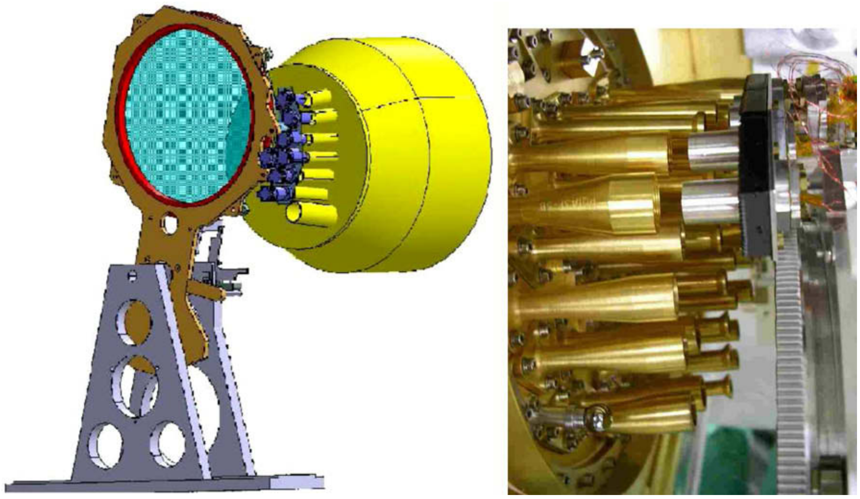

Fig. 1. Schematics and picture of the fibers setup facing HFI focal plane (which cold optics is represented by the right hand side box on the drawing and which is on the left on the picture).

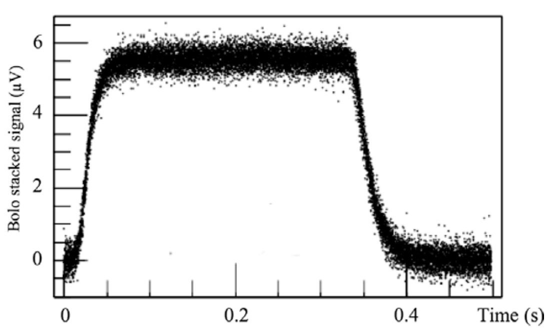

Fig. 2. Stacked signal of one HFI bolometer from the qualification model.

2.3. Requirements

Taking into account the constraints of the previously described experimental setup, and the needs for the HFI characterizations, the requirements for developing these carbon fibers were threefold:

- To get a signal ranging up to a few pW detected on the HFI bolometers for the concerned frequencies (ranging from 100 to 857 GHz) including transmission efficiency of the cold optics horns and integration over the 30% wide frequency bands.
- To get a relatively small time constant (smaller than 10 ms) and a repeatable signal in a pulsed regime, allowing to stack the measurements and increase the signal over noise ratio.
- To be able to switch on the fibers without introducing any parasitic signal due to EMI-EMC from the electrical pulse used to drive them.

The carbon fibers did meet these requirements. Even more, on the time constant issue, the fibers were finally included in the list of sources used to characterize the time response of the instrument. Fig. 2 shows an example of one bolometer signal induced by a pulsed fiber. The quality of the fiber data revealed the presence of a second slow time constant below the percent level on some bolometers [4]. This defect has been understood and mastered thanks to an additional dedicated run during 2008 summer at the Liège CSL, for which a new device including the fiber sources has been built.

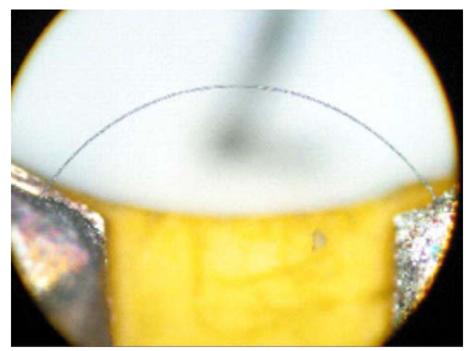

Fig. 3. Photography of one of the carbon fiber used for the Planck-HFI calibration: the diameter is 6 μm and the length $\sim$ 1 mm.

3. Fiber device and electronics

3.1. The fiber device

One of the authors suggested to use carbon fibers, since their resistivity does not fall to zero at low temperature, which allows to easily warm them through Joule effect. Besides, the good surface over volume ratio of a fiber should allow to reach a sizeable emitting surface with a tiny amount of matter, and 1 mm long fiber should behave as good antennas for mm range or smaller wavelengths.

We used on the shelf carbon fibers[1] which happened to fulfill our requirements. The work presented here allowed us to quantify *a posteriori* the reasons of the fiber behaviour.

The physical properties of materials at low temperature depend much on their fabrication procedures, so the results on heat capacity and thermal conductivity shown hereafter are specific to the fiber we used. But, they certainly give a good indication of a generic behaviour of carbon fibers.

Photography on Fig. 3 shows a typical fiber. Our fibers have length $L \sim 1$ mm. The diameter of a slice is 6 μ. They are glued and thermalized at each end on a Kapton–Copper circuit by a drop of Ag lacquer on an extra fiber length of about .25 mm on each side. Kapton thickness is .09 mm and Copper layer thickness is .04 mm.

[1] $\varnothing$ 7 μ $\times$ 12 mm fibers, labelled BESMGHT, Grade IM 500 $\times$ 12000, bought in 1994 by AKZO Fibers SA, F 69626 Villeurbanne Cedex, France.