IBIS STM: Mechanical and Thermal Model, Design and Tests

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ABSTRACT The IBIS Structural and Thermal Model, STM, is the first instrument model to be completed during the development phase of IBIS. According to the STM planning the Spacecraft integration was in April/May, and the test program lasts from June to October 1998. This paper describes mechanical design choices and implementations, as well as results from environmental testing. Analysis and tests will verify the validity of the design in view of the two major questions that have been faced in the STM design: detector weight and thermal design. Details will be given on the main parts of IBIS, like the Mask (188 kg), the Detector Structure (71 kg), and the heavy shielding both active (193 kg) and passive. Finally the thermal problem connected to the large number of detectors (about 20.000 pixels) will be discussed.

1. INTRODUCTION

IBIS is one of the two main instruments on the ESA space mission INTEGRAL (INTErnational Gamma Ray Astrophysics Laboratory). IBIS (Imager on Board INTEGRAL Satellite) will provide images with few arc-minute resolution of the gamma-ray sky from 20 keV to 10 MeV. The main components of IBIS are two detector planes and a coded aperture mask.

The first detection plane is composed of about 16000 cadmium-telluride, CdTe, elements, while the second detection plane is composed of 4096 caesium iodide, CsI(Tl) - thallium activated - scintillation crystals viewed by photo-diodes. The sides and the "bottom" of the detector planes are surrounded by an active "veto" shield of BGO crystals, while a passive collimation system, named Hopper and Tube shield, defines the solid angle viewed by the IBIS detector to the (fully coded) field-of-view for energies up to a few hundred keV. Other units are the Calibration Unit, and seven electronic boxes (for more details, see *P. Ubertini*, in these proceedings).

The development and verification plan for the IBIS instrument foresees a series of "models" leading to the final flight instrument. Different sub-systems in IBIS have different development plans, and thus different types and number of models. However, the first instrument model, the structural and thermal model (STM), comprises all IBIS sub-systems and units. The IBIS STM is representative of the instrument flight design in terms of mechanical structure and thermal control hardware. The IBIS STM Mask is actually a full qualification model. Other units are representative for mass, stiffness, mounting, shape and internal power dissipation. Testing of IBIS STM includes structural tests, both at instrument and satellite level, whereas thermal test are performed only at space-craft level.

The major design features, and some results of the tests are reported in the following. The agreement with the previsions, and the good performance of the Model will be described.

2. MECHANICAL DESIGN

2.1 Mounting concept

The Mask, the Detector Unit, the seven Electronic Boxes, and the Calibration Unit are all mounted independently on the Pay-Load Module, PLM. The Mask is mounted 340 cm above the Detector Bench on the PLM H-shaped structure. The Main Frame of Detector Unit is bolted to the PLM Detector Bench (by 24 M8 screws). The Electronic Boxes are mounted on the Detector Bench in two groups along the +Y and -Y sides, and the Calibration Unit is mounted 220 cm above the Detector Bench on the -Y wall of the H-structure. Finally, the Tube Shield is part of the PLM structure. The area of the Mask is 1180 x 1142 mm. The footprint of the Detector Unit is 940 x 940 mm, and its height is 850 mm.

2.2 Design drivers

The three major mechanical design drivers aimed at: 1) providing redundancy and modularity for reduced single point failure loss (max. 20% in the Detector), 2) minimizing the instrument weight, and 3) optimizing the Detector thermal conductivity. This has been obtained in the following way. The Veto detectors, and the Detector layers (ISGRI, PICsIT) are composed of respectively 16, 8 and 8 identical modules (actually the Veto detectors are of three slightly different sizes, see *P. Sarra* these proceedings). The tungsten plates (154 kg) of the Mask are supported by a carbon fibre (CFRC) honey-comb structure weighing 29 kg. The Main Frame (fig. 1) is machined from one piece of aluminium (AA 7075). The initial weight of the Al-block was 960 kg, and the final weight is 59 kg. In the Hopper the tungsten sheets are supported by a carbon fibre structure.

2.3 Weight distribution

The total weight of IBIS STM is 683 kg (including the Tube shield). The mass and the relative weight (in percent) of the other sub-systems and units is shown in table 1. It can be seen that the weight of the Detector Unit is 381 kg, or about 55% of the total weight. However the actual detectors layers, ISGRI and PICsIT, amounts to only 11% of the total weight of IBIS.

3. THERMAL DESIGN

IBIS consists of physically separate items as described above, and they need independent thermal control. The thermal design is passive, and is constrained by 1) the PLM thermal environment, including two radiators, 2) the temperature limits of the different items, in particular the gamma-ray sensors, and 3) the internal power dissipation. In this paragraph we shortly describe the thermal design of the Detector Unit. The heat load inside the Detector is given by the power consumption of the CdTe layer electronics (44.8 W), the CsI layer electronics (40.0 W), and the Veto Module electronics (25.9 W) for a total of 110.7 W. The in-orbit temperatures of the IBIS Detector main parts have to satisfy certain temperature limits. The design critical temperatures are the maximum temperature in operating conditions (+22 °C), and the minimum temperatures (-20 °C) in the non-operating (switched off) condition for the two detection layers. Note that both of them utilises semiconductor devices, respectively CdTe and Si. After extensive mathematical modelling, and some experimentation, the following design solutions are adopted.

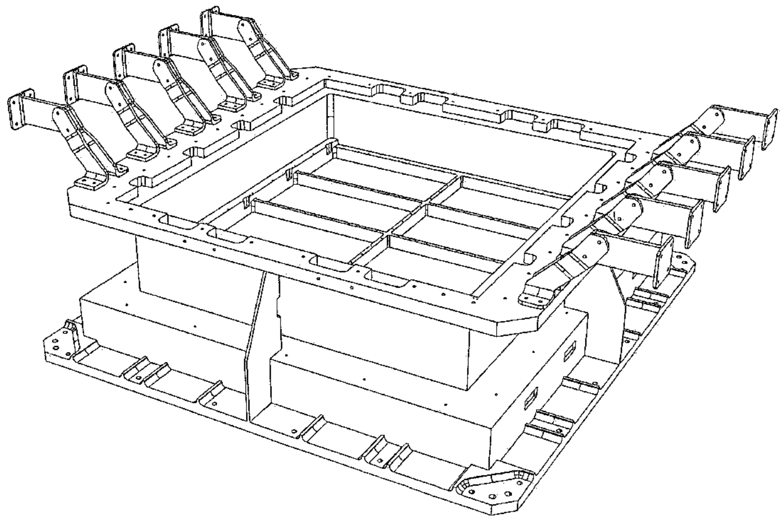

FIGURE 1. Detector Main Frame with thermal straps for connection to the two radiators. For dimensions and weight see the text.

Heat flows from the Detector Unit to the PLM by means of:

- Top shields on the ISGRI CdTe crystals optimised for high emissivity, good EM shielding and very low X-ray absorption
- High emissivity surfaces of the Hopper and the Main Frame
- Conductive straps between the Main Frame and the two PLM Radiators (-Y and +Y sides) see figure 1
- Low thermal resistance between the Main Frame and the Detector Bench (baseplate)

Moreover, some heaters are included in the Detector, and they are activated during non operative conditions to maintain the ISGRI and PICsIT temperatures above -20 °C. A heater is a thin sandwich (max. thickness: 0.2 mm) with a resistive body between two kapton sheets. The resistive material is a "superalloy" based on nickel with a typical thickness of 0.03 mm. The heater material absorbs X-rays. For PICsIT, having the low energy threshold above 100 keV, the heaters are glued to the cover of the detection modules. While for ISGRI the heaters are glued to the beams of the ISGRI Spider (support structure) thus avoiding to cover the CdTe modules. The chosen implementation is optimised in order to reduce the power consumption, given the constraint of no-coverage of the x-ray detectors. About 100 W are needed to reach -20 °C over the CdTe Layer during IBIS non operative condition. For PICsIT heaters the required power is about 40 W, giving a total heater power

ITEM	D. U. (kg)	IBIS (kg)	IBIS (%)
MASK total		188,2	28
Calibration Unit		12,0	2
Tube Lead Shield		46.0	7
HEPI, IREM, Harness		7,3	1
Electronic Boxes		48,8	7
HOPPER	36,6	36,6	5
ISGRI CdTe layer	16,2	16,2	2
PICsIT CsI layer	63,2	63,2	9
VETO Modules	193,2	193,2	28
Detector Structure	71,4	71,4	11
Detector Unit total	380,6		
IBIS total		682,9	100

TABLE 1 Mass and relative weight of IBIS STM and its sub-systems.

of 140 W. Both heater systems comprise nominal and redundant heaters (in cold redundancy).

4. THERMAL TEST RESULTS

The INTEGRAL STM satellite thermal balance test has been carried out at ESTEC testing facilities (Holland) inside the Large Space Simulator in the following basic environmental conditions: Chamber pressure $<10^{-5}$ mbar, shrouds temperature 100 K, solar flux 1320 or 1423 W/m^2. During tests both coast and nominal orbit phases have been simulated, as well as eclipse and stop of illumination. The highest and lowest temperature values reached during steady states in the various test phases are shown in table 2 for significant items of IBIS. The Mask is typically the coldest item on IBIS, as expected.

Condition	MASK	Cal. Unit	D. U. structure	CdTe module	CsI module	Elec. boxes
Hot case	+9.3	+6.3	+7.2	+6.4	+10.2	20.8
Cold case	-30.2	-24.8	-23.7	-20.7	-14.7	-9.8

TABLE 2 Measured temperatures (°C) during space-craft testing.

Comparing with the previous paragraph it can be seen that the thermal design of IBIS, and in particular the Detector thermal control concept, is successful.

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