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BepiColombo MIXS Focal Plane Assembly

From Concept Design to Proto-Flight Model

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***Abstract*— This paper describes the thermo-mechanical design of the BepiColombo MIXS (Mercury Imaging X-Ray Spectrometer) Focal Plane Assembly (FPA) Proto Flight Model (PFM), with references to the preliminary design and the evolution of the design.**

An outline of physical testing already performed to gain confidence before the PFM campaign is also given.

***Index Terms*— Focal plane assembly, BepiColombo, X Ray, DEPFET**

I. Introduction

MIXS will be launched in 2015 as part of the ESA/JAXA's BepiColombo mission, and will reach Mercury in 2022. Once in orbit, MIXS will provide an insight on the formation and evolution of Mercury. For this purpose, MIXS will explore the chemical composition of Mercury's crust, measuring fluorescent X-Ray emission from the planetary surface with the aid of X-Ray DEpleted P-channel Field Effect Transistor (DEPFET) Detectors.

The MIXS instrument (see Fig. 1.) consists of two complementary X-Ray instruments:

- MIXS-T, composed of an FPA and a telescope (MOM-T, MIXS Optic Module Telescope)
- MIXS-C, composed of an identical FPA and a Collimator (MOM-C, MIXS Optic Module Collimator)

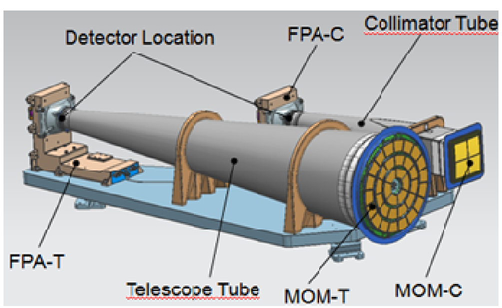

Fig. 1. MIXS Instrument

The main task of the MIXS FPA is to support the X-ray Detector, together with the Proximity and Front End Electronics. The Detector needs to stay below -45ºC not to accumulate radiation damage. For this purpose, a passive cooling system is provided by the spacecraft. The Cold Finger's cooling power at -45 ºC is 1.7W, while the Proximity Electronics dissipates 2.2 W. This fact dictated the separation of the Detector from the Proximity Electronics.

Because of this separation, the 370+ bond wires connecting the Detector to the board are now subjected to mechanical stresses with each displacement of the Detector relative to the board. Maximum allowable displacement under any handling, launch or operating load was estimated as 50µm.

A very stiff support is needed which can at the same time hold the Detector and the Proximity Electronics Board with very small relative displacements whilst minimizing the heat flow from the Proximity Electronics Board to the Detector.

II. Main Requirements and Boundary Conditions

The main requirements to be met by the FPA are summarized in TABLE I.

TABLE I. Main Requirements summary

TYPE	ITEM	UNITS	VALUE
MECH.	Mass	g	<1300
	First Eigenfrequency	Hz	>150
	Detector's First Eigenfrequency	Hz	>400
	Detector-to-Hybrid displacements	µm	<50
THERM.	Detector Temperature	ºC	<-45
	S/C I/F Temperature	ºC	-20<T<+40
	Cold Finger I/F Temperature	ºC	-60 @ 0W -45 @ 1.7W

From the main requirements listed in TABLE I. the most critical is the compromise between thermal isolation and stiffness.

III. Design Description

Both the concept of the MIXS instrument and the S/C have evolved since the preliminary design of the MIXS FPA was finished back 2008 [1]. This has forced some changes in the design of the FPA:

- Each FPA is now joined to a Tube which supports its respective MOM (MIXS Optics Module), using the FPAs as one of its structural supports
- The FEE is now located below the DPA, in horizontal position, and the connectors are on the other side
- The Detector Thermal Strap exits now on the back side of the FPA and a new TRP Thermal Strap has been added
- Mechanical loads have increased

Even though these modifications have changed the whole concept of the FPA, the main part, the DPA, has only changed because of the stiffening and lightweighting process, proving it was a robust conceptual design.

A. General

Fig. 2. shows a general view of the FPA design. Four main parts and assemblies are identified:

- DPA: Provides a stiff but thermally and electrically isolating mechanical interface between the Detector and the Structure, together with mechanical support for the Hybrid.
- FEE Card: Contains the Front End Electronics
- Structure Assembly: Provides mechanical support and radiation shielding for both the DPA and FEE card
- Thermal Strap: Provides a conductive path between the Detector and the spacecraft's Cold Finger. It incorporates also the Temperature Sensor and Annealing Heaters.

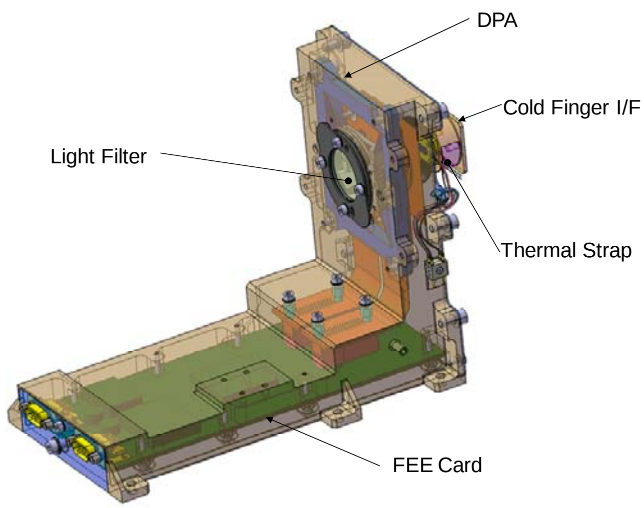

Fig. 2. MIXS FPA General view

B. DPA

The DPA is the key element in the design, as it has major influence in the fulfillment of most of the requirements. A general view with nomenclature can be seen in Fig. 3.

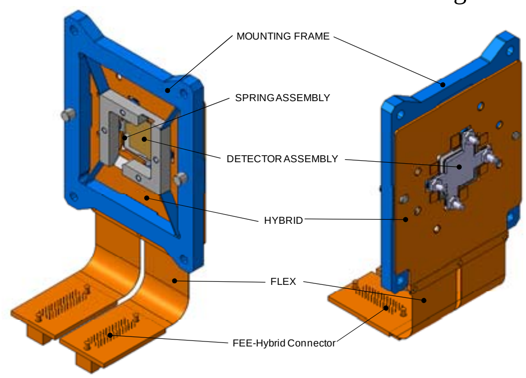

Fig. 3. DPA General view

Main functions of the DPA are as follows:

- Provide a high stiffness/low conductance Detector support
- Provide support for the Hybrid
- Allow wire bonding of Detector to Hybrid
- Provide a Spring Clamp in case the glue fails
- Electrically isolate the Detector

1) Detector Assembly

The central part of the whole MIXS FPA is the Detector. This is a DEPFET device provided by MPI-HLL (see [2]) which is supported by the Detector Assembly (see Fig. 4.):

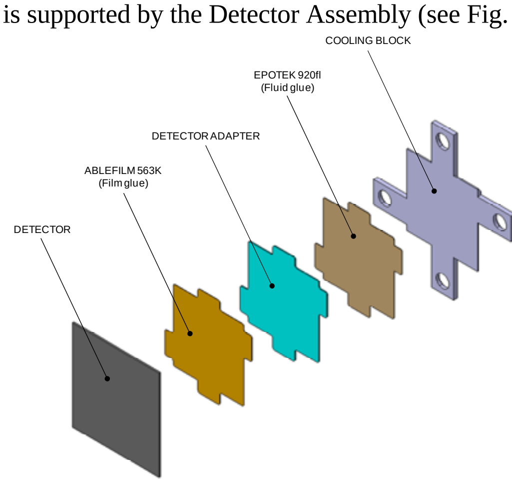

Fig. 4. Detector Assembly (exploded view)

The Detector is glued to the Detector Adapter by means of a sheet of Ablefilm 563K. The Detector Adapter is a flat part made of AlN which provides a highly conductive path from the Thermal point of view while electrically isolating the Detector from the Cooling Block, and a reasonable CTE (Coefficient of Thermal Expansion) match to both the Detector and the Cooling Block. The Detector Adapter is bonded to the Cooling Block by means of Epotek 920FL.

The Cooling Block has evolved to become a flat part, although it conserves its odd shape driven by the Detector accessibility requirements.

2) Mounting Frame

The Detector Assembly is bolted to the Mounting Frame. This part, made of Ti6Al4V, interfaces the Detector Assembly to the Bracket by means of 4 flexures (see Fig. 3.), providing an overall conductance of $6 \cdot 10^{-3}$ W/K. First measured eigenfrequency of the hard-mounted assembly is 1130 Hz.

Previous design provided a lower conductance, $4 \cdot 10^{-3}$ W/K, but also lower stiffness, 440 Hz, which was proven not enough to guarantee survival during launch.

Part of the mounting frame is covered by Sheldahl 146385 First Surface Aluminium Coated Polyimide Tape, which reduces power income from 0.15 W to less than 0.05 W.

3) Hybrid + Flex

The Hybrid contains the proximity electronics for the Detector. It is provided by MPI-HLL (see [2]), with the Flex cable already assembled. The Hybrid is bonded to the Mounting Frame in the outer edges.

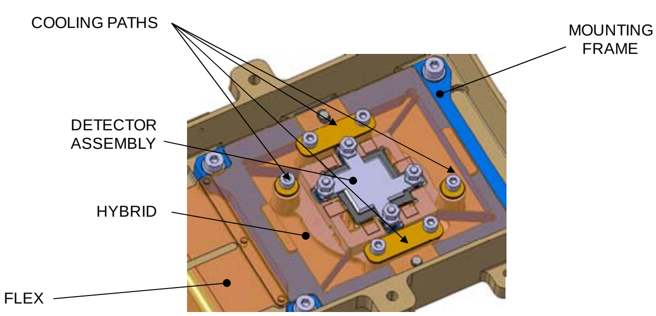

Fig. 5. Hybrid supporting to the Mounting Frame and to the Front Bracket

Direct cooling paths through the DPA Bracket (see below) are also provided to guide heat from the Hybrid directly to the Bracket and not to the Frame

C. Structure Assembly

Main requirements for the structure are as follows:

- High stiffness and Low mass
- Low dynamic load amplification
- Support the DPA and the FEE
- Provide an efficient cooling path for the Hybrid and the FEE
- Provide structural support for the MOM tube
- Radiation, EMC shielding and light shielding

The Structure assembly is made up of the following parts (see Fig. 6.):

- DPA Bracket
- DPA Cover
- Lower Cover
- Components: TRP, Light Filter, Calibration Sources

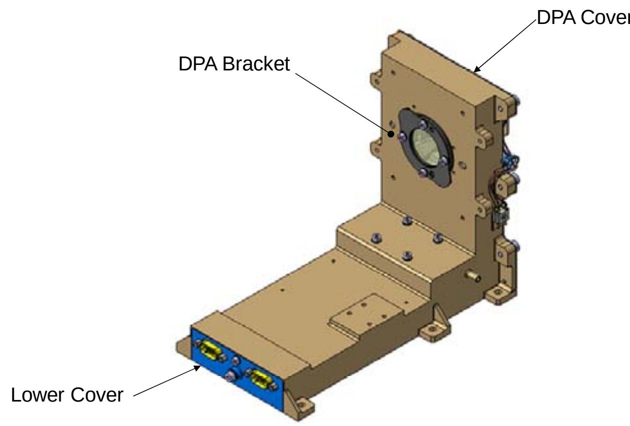

Fig. 6. MIXS FPA Structure Assembly

The DPA Bracket is responsible for all the requirements for the Structure Assembly.

It is an L-shaped bracket with provisions for FEE, DPA and MOM tube supports, as shown in Fig. 2. It is made of aluminium because of the high stiffness-to-weight and conductivity-to-weight ratios.

Support for the Monitoring Sources is provided in the front face (Fig. 7.). A blind allows radiation to reach only the allowed area.

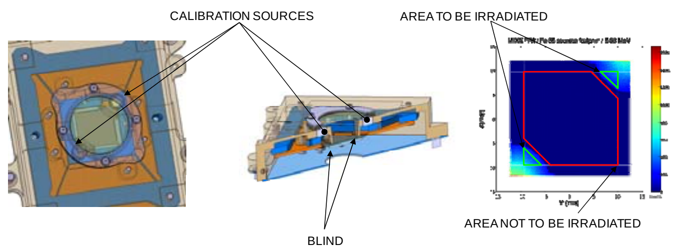

Fig. 7. Reference Sources

The back side of the FPA is closed by a thin aluminium DPA Cover, except for an aperture through which the Heater Pad provides an I/F for the Thermal Strap.

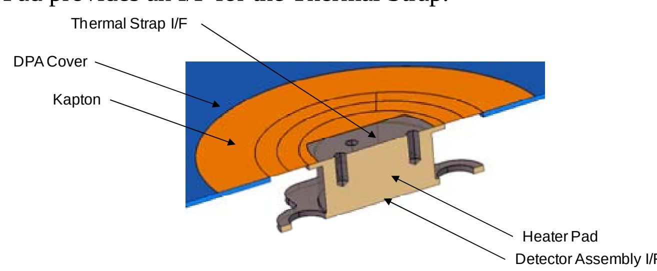

Fig. 8. Detector-Thermal Strap Interface

The gap between both parts is covered by the Kapton, providing air and light tightness. In order to minimize parasitic heat load into the Cold Finger (DPA Cover is at ~S/C temperature Heater Pad at ~Detector Temperature), a thin (25 µm) black Kapton film (100CB) has been chosen. This film is bonded by means of 3M 966 PSA. Maximum thermal load through the Kapton is below 15 mW.

The lower side of the DPA Bracket is closed by a thin aluminium Lower Cover.

D. Thermal Strap Assembly

The Thermal Strap assembly has evolved deeply because of the modification of the Cold Finger Location.

Its main component is the Thermal Strap, a custom development because of the extremely low stiffness needed.

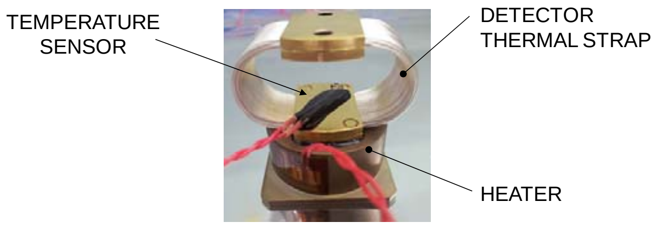

Fig. 9. Thermal Strap Assembly

The Detector Thermal Strap is made of OFHC silver coated copper wires to provide a conductive Cross Section of 30 mm^2. Terminals are made of Gold coated OFHC Copper.

The assembly includes also the Annealing Heater, a custom Kapton heater provided by MINCO that can deliver up to 34W, and a 1000 Ohm PRT (Platinum Temperature Sensor).

E. FEE Card

The FEE Card is provided by the University of Leicester.

It has two connectors for the Hybrid (ESA3401-065-01B-052-13-30-112) and two more for the Harness (DEM15) as shown in Fig. 10. It is sandwiched between the FPA Lower Cover and the FPA Bracket by means of 8 M3 Bolts.

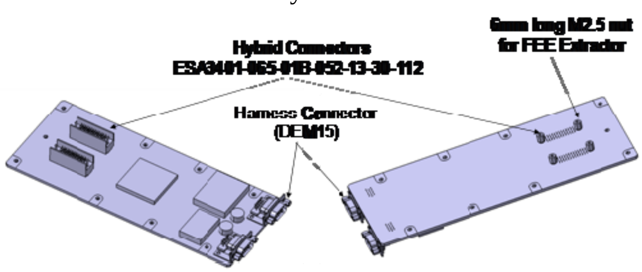

Fig. 10. FEE Card

F. Light Filter

A Light Filter is positioned in front of the Detector. It is a Ø30.2mm clear aperture, 1500Å aluminium film deposited on 8000Å Polyimide substrate, provided by LUXEL.

IV. Development and Validation Overview

Exhaustive testing with increasing level of complexity has been performed in order to guarantee FPA qualification at PFM level and, specially, BondWires will survive launch loads. The most important are listed below:

Structural tests:

- DM (Development Model) #1
    - DPA level test
    - Visual inspection after each test
    - Sine loads up to 45g (150 µm peak displacement)
    - Random loads up to 0.7 g^2/Hz (launch conditions at the time)
- DM #2
    - DPA level test
    - Visual inspection after each test
    - 86000 displacement cycles of ± 100µm
- DM #3
    - FPA level test
    - Real-time BondWire condition monitoring plus visual inspection after each test
    - Random loading:
        - Qualification Level, 10xQualification time
        - 2xQualification Level, 2x Qualification time
        - 3xQualification Level, 2x Qualification time
- DM #4
    - DPA level test
    - Real-time BondWire condition monitoring plus visual inspection at end of test
    - Sine tests close to resonance to obtain 30, 40, 50, 60, 70 and 80µm, 4 minutes duration each
- STM
    - FPA level test plus MIXS level test
    - 2 specimens
    - Launch loads
- STM2
    - MIXS level test
    - BondWire condition monitoring between tests plus visual inspection at end of test campaign
    - Launch loads

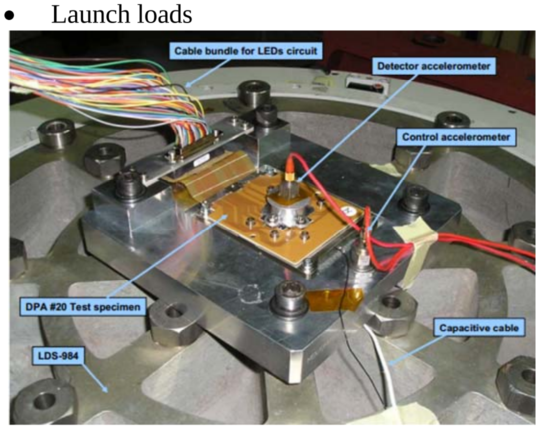

Fig. 11. DPA DM #4 sine vibration test

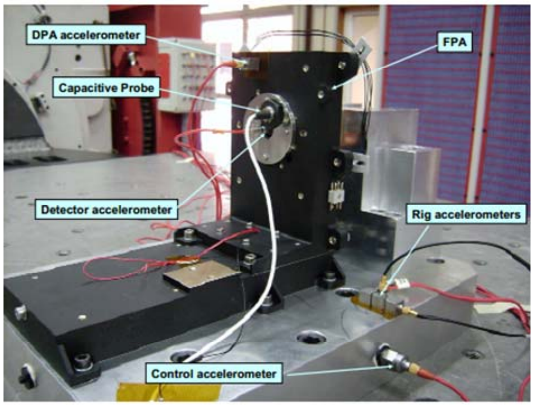

Fig. 12. STM FPA level vibration test

Thermal tests:

- DM
  - DPA level test
  - Thermal concept and model validation
- STM
  - FPA and MIXS Level test
  - Thermal concept and model validation

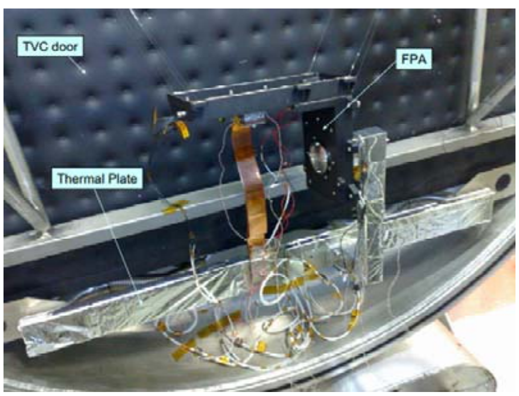

Fig. 13. STM thermal vacuum test

Component testing

- Light Filter
  - Vibration
  - Acoustic
- Thermal Strap Qualification
  - Stiffness
  - Thermal Conductance (air and vacuum)
  - Dynamic loads
  - Life

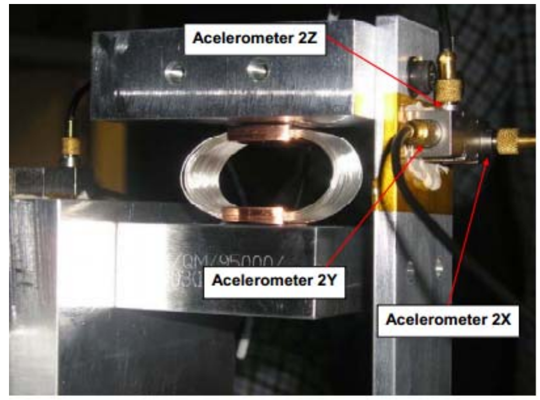

Fig. 14. Thermal strap life Test

EMC test campaign is to be performed prior to PFM campaign in the 4th quarter 2012.

V. Outlook

Following steps are foreseen:

- Perform FPA Qualification test campaign (including EMC, structural and thermal vacuum tests)
- Deliver PFM FPAs (currently under production)
- Deliver Flight Spare FPA

Acknowledgment

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[1] J. San Juan et al., “MIXS focal plane assembly”, Proceedings of the SPIE, Volume 7011, pp. 70112S-70112S-11 (2008).

[2] P. Majewski et al., “Integration and calibration of DEPFET macropixel detectors for MIXS”, High Energy, Optical, and Infrared Detectors for Astronomy V, in press