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# HiPeG: A POINTING AND STABILIZATION SYSTEM FOR HARD-X-RAY TELESCOPES WITH FOCUSING OPTICS

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Very recently, a wide range of techniques are being developed which enable efficient focusing of hard X-ray radiation. Large area, long focal-length X-ray optics are being developed based on grazing incidence reflection as well as Bragg and Laue diffraction. These devices will be characterised by very large focal lengths, typically 5-10 m and a relatively high angular resolution, typically much better than 1 arcmin. These features are a major concern in view of an implementation of these telescopes on board balloon-borne platforms. In fact, the long focal length will require high aspect ratio telescope structures and, more importantly, the high angular resolution will demand high pointing accuracy and stability of the platform.
Starting from the experience of the LAPEX experiment, we are concentrating our effort in finding the most effective solutions with which to achieve the required pointing accuracy and stability of our next balloon gondola (HiPeG). Our goal is to achieve a pointing accuracy of ±30 arcsec with a *post-facto* pointing knowledge of ±15 arcsec or better. The system will be based upon a GPS system combined with a high precision reaction wheel. A newly developed, high dynamic range star sensor will enable fast pointing reconstruction at the arcsec level.

| **X-RAY OPTICS: EXPECTED PERFORMANCES** | ***Grazing incidence (propos. Merate)*** | ***Bragg diffraction (HAXTEL)*** | ***Laue diffraction (CLAIRE)*** |
|---|---|---|---|
| ***Energy range (keV)*** | 30-70 | 60-150 | 170 |
| ***Focal length (m)*** | 6 | 5 | 2.76 |
| ***Field of view (arcmin)*** | 10 | 80 | 1.3 |
| ***Effective area ($cm^2$)*** | 18/unit (@40keV) | 100 (@80keV) | 94 (@170keV) |
| ***Angular resolu. (arcsec)*** | 30 | 60 | 15 |

## Technical description

The need for a high precision attitude control system for high altitude balloon experiments was initially triggered and motivated by the project CLAIRE [La Porte et al, 2000]. In fact the performance of this experiment (see table above) calls for the best pointing accuracy ever needed on a balloon experiment.

On the other hand, the TESRE Institute has a consolidated experience of several decades of activity in the field of high altitude balloon experiments, and in particular in hard-X-ray experiments. The Lapex experiment [Frontera et al,1984], whose last flight took place in 1995 from Fort Sumner, is an example of a highly complex system whose pointing capabilities can be adopted as the lower limit of the requirements of the new generation X-ray telescopes. Therefore, the Lapex gondola, with all its subsystems, constitutes the ideal starting point for the design of the new system

In the final configuration the telescope will be supported by an azimuth-zenith pointing mount. There will be an attitude control electronics, a transmit/receive radio system and the ballast for altitude stabilization of the balloon, for a total weight of approximately 1500 kg.

In the present design of the attitude control of the gondola, there is a motorized pivot between the balloon cord and the gondola and a reaction wheel placed on the gondola. A prototype of the reaction wheel is already available and a number of tests have already been performed. The preliminary results are shown below.

The final pointing trajectory of the X-ray optics at the arcsec level will be reconstructed using a new star/sun sensor based upon a high dynamic range, cooled CCD detector. This system will provide a night and day pointing precision of 15 arcsec with a refresh every second. The components of this system are already available and the first tests will start soon.

The attitude control will be based upon a magnetometer and a GPS system. The latter will provide the information for the absolute attitude control down to the arcmin level. Below this level, the information on the pointing offset will be obtained from the star/sun sensor. This information, fed into a DSP (Digital Signal Processing), will provide the current required to control the motors for the azimuth-zenith axis of the experiment.

The entire control system will resemble that used for the Lapex experiment [Silvestri, 1994]. An On Board Computer will perform real-time calculations of the co-ordinates of the target object, will process the image provided by the star/sun sensor to extract possible off-sets and will feed the DSP with the data required to move the telescope to the next position. This procedure will be repeated with a very high frequency (~1Hz) to ensure effective tracking of the source.

A specific software will be developed starting from the Lapex framework, which will enable the user to send and receive control strings, to acquire and display the status of all subsystems and to perform preliminary scientific data analysis.

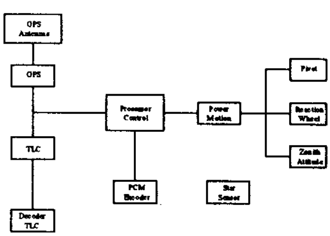


**Fig. 1 On Board System**

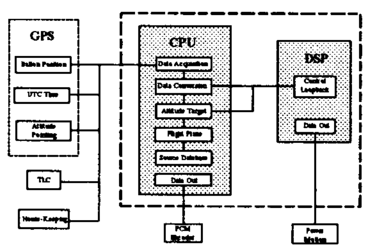


**Fig. 2 Processor Control**

## STAR/SUN SENSOR

The core of the star/sun sensor is a cooled CCD array. Presently, this detector is a 768x512 KAF array with 9x9μm pixels and a 12-bit ADC. At the max readout speed of 1MHz and at a CCD temperature of 10°C the measured noise (electrons/RMS) is 10.

Presently this detector is being tested using a 500mm fixed optics. With the above pixel size, the geometric angular resolution of the system will be around 4 arcsec/pxl. In the final configuration a zoom lens may be necessary to ensure the best matching between required angular resolution and pixel size.

## GPS Specifications

**Attitude** ½ Sec. Update, unsmoothed

| | | | | | |
|---|---|---|---|---|---|
| **Static** | Antenna Baseline | 1 meter | **Dynamic** | Antenna Baseline | 1 meter |
| | Heading | 0.13° rms | | Heading | 0.07° rms |
| | Pitch & Roll | 0.23° rms | | Pitch & Roll | 0.10° rms |

**Pointing Accuracy:** If we assume that the relative position error is 1 millimeter and if the baseline length between two antennas is 1 meter, the pointing accuracy of that baseline would be within 1 milliradian.

Increasing the baseline lentgh to 2 meters wolud result in a pointing accuracy of 0.5 milliradian.

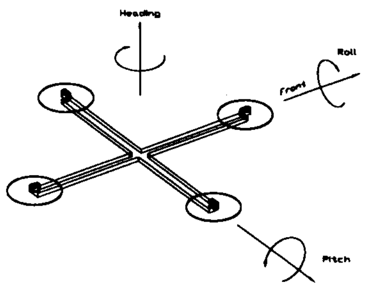


**Fig. 3 Array GPS Antennas**

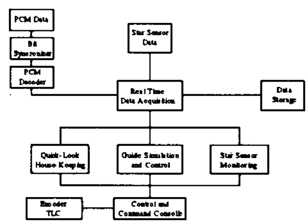

**Fig. 4 Ground Support Equipment**

**First Results:** It should be remembered that these first results were obtained using the LAPEX platform with its magnetometer (and not a GPS system as foreseen for the final version); and also prototype versions of the platform reaction wheel and of the DSP software.

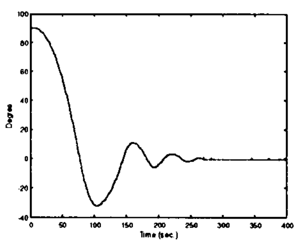

**Fig. 5 Large Offset Test**

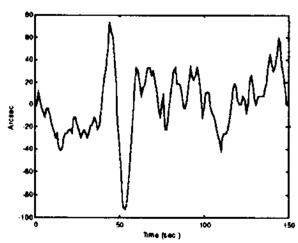

**Fig. 6 Stabilization Test**

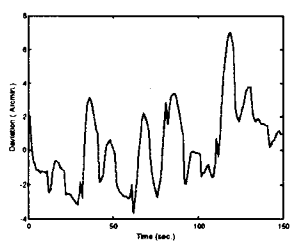

**Fig. 7 Tracking Test**

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