## An X-ray Attitude Sensor for Spin Stabilized Satellites

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# Introduction

Recent advances in the design of microsatellites have led to renewed interest in the missions that can be flown with small spacecraft and small payloads. The CubeSat platform and the Plug-and-Play concept have prompted the development of attitude determination hardware that are, thus far, typical of larger, more sophisticated, three axis stabilized spacecraft. These include miniature gyroscopes, reaction wheels and star cameras. The X-ray Star Scanner (XSS) is a new class of attitude sensor, designed to support precision spin-stabilized CubeSat missions by providing arcminute attitude accuracy in a size compatible with a CubeSat. The scientific and technological advances necessary to make this instrument possible are in place. A robust catalog of x-ray guide stars is available through several all-sky surveys performed in xrays. Solid state x-ray detectors and their related support electronics have been flown. The concept of using guide stars to determine the attitude of a spinning vehicle has been demonstrated using flight data. The XSS fills the need created by the CubeSat and Plug-and-Play platforms for accurate attitude determination on a spin stabilized platform provided in a small package.

# X-ray Star Scanner Concept

The X-ray Star Scanner provides a new method of attitude stabilization for CubeSats: the precision spin stabilized microspacecraft. Spin stabilized satellites have been used for over 40 years to perform earth observing, space physics and astronomy missions. They are inherently stable, typically naturally in a sunsafe configuration and do not require complex, active attitude control hardware to function properly. The XSS will allow these small, capable platforms to be pointed with arcminute accuracy, regardless of the spin rate of the vehicle. This is a two order of magnitude improvement over what can be achieved by a magnetometer/sun-sensor combination and an order of magnitude better than could be achieved with a horizon-crossing indicator, if one were available for use on a CubeSat. Furthermore, the XSS operates in eclipse (unlike a sun-sensor), at high orbits (unlike a magnetometer) and in any orientation (unlike a horizon-crossing indicator). The only other instrument that offers comparable attitude determination performance is an imaging star camera, but these are not useful on a spinning spacecraft and in order to achieve their miniaturization, are based on COTS hardware.



The XSS consists of three primary components (Figures 1 & 2):

- 1. A collimator that establishes the instrument field-of-view in both the direction of spin and perpendicular to it.
- 2. An x-ray photon detector that registers the arrival of each x-ray photon
- 3. The detector electronics that read out the photon events, place them in the appropriate time bins and pass the data stream on to the navigation algorithms
- 4. A processor to determine the orientation and spin rate of the spacecraft based on the pattern of stars observed.

As the spacecraft spins, the collimator on the XSS sweeps an arc across the sky. As the spacecraft rotates, the x-ray guide stars enter and leave the instrument FOV, defined by the collimator. Pulses of x-ray photons are recorded and a series of collimator response functions are fit to the data. These pulses form a unique pattern that is indicative of the orientation of the spin axis relative to the pattern of guide stars in the sky, as shown in Figure 3. By matching the pattern to a catalog of guide stars, the direction of the spin axis and phase of the spin can be determined. The spin rate can be determined without reference to a catalog by noting the period of the repeating pattern of guide stars (e.g. taking the Fourier transform of the repeating pulse train). This concept was demonstrated using archived flight data from the HEAO spacecraft, showing sub-arcminute resolution can be achieved<sup>1</sup>.



Figure 4: XSS Raw Input Signal

The components necessary to build the XSS have proven flight heritage. X-ray collimators have been flown on numerous x-ray telescopes, including, but not limited to, Uhuru (1973), HEAO (1979) and the recent Unconventional Stellar Aspect Experiment (1999). A number of all-sky catalogs in the soft X-ray regime have been produced, including a detailed catalog compiled by ROSAT in 1999<sup>2</sup>.

There are several well established and proven options for the detector. The XSS does not require an imaging detector, since it creates the "images" of the guide stars by scanning the collimator over them. As such, the readout electronics are greatly simplified and any of the available x-ray detector technologies could be used. These include microchannel plates, silicon strip detectors, and x-ray CCD's. Proportional chambers have been used extensively for x-ray astronomy as well, but they are not appropriate for the XSS owing to the lifetime and packaging issues associated with the fact that they are filled with gas that must be replenished and maintained at constant pressure. The selection of the detector will involve a trade-off between cost, support electronics, and the energy band over which the detector is sensitive to x-ray photons.

The final piece of the XSS is the processor with its navigation algorithms. By designing the navigation algorithms to minimize computation time, the processing requirements for the XSS will not be extensive, particularly once the initial attitude is established and the instrument can transition to an "update mode" where the entire catalog need not be searched. We anticipate that the XSS will be compatible on a mass,

volume and power basis with a CubeSat 3U form factor. Preliminary estimates suggest that an XSS that is 4 cm by 9 cm by 8 cm in size will provide arcminute pointing accuracy. Typical imaging x-ray CCD cameras use on the order of  $0.05 \text{ W/cm}^2$  of collecting area, leading to a power estimate of 1.8 W for the 36 cm<sup>2</sup> unit. This estimate is high, since the XSS detector does not require electronics capable of clocking data and reading out regular multipixel images. The XSS uses a single pixel detector and should require much less power. A simple FPGA for processing the XSS data will require less than 200 mW of additional power and can provide the interface necessary for Pug-n-Play compatibility.

### X-ray Star Scanner Enabled Missions

The X-ray Star Scanner will provide a precision attitude reference for spin-stabilized spacecraft with a design targeting CubeSat class spacecraft. However, this attitude sensor will be useful to any spin-stabilize spacecraft requiring arcminute level attitude determination accuracy such that the X-ray Star Scanner will be useful on a host of small spacecraft platforms being developed. This instrument will enable new missions by providing arcminute level point accuracies for spacecraft supporting key missions such as: Earth mapping and observing missions; solar and astronomical observatories; space weather missions; and planetary, lunar and asteroid mapping and observing missions. There are several obvious DoD applications for precision spin stabilized spacecraft, including electronic intelligence, space weather observations, rapid responsive space communications satellites and earth observing spacecraft in Thompson Spinner configurations, in which the spacecraft spin axis is aligned with the orbit normal. This allows a simple linear array to be swept over the Earth, imaging a swath of the Earth's surface as the spacecraft orbits. These spacecraft could produce detailed multispectral images of the Earth's surface on a recurring basis, with image registration on the order of 100 m from an altitude of 400 km, all in a compact CubeSat form factor and capable of quick turn-around and launch on an as-needed basis.

As the CubeSat concept becomes more accepted, the potential uses for, and users of, the XSS will grow. For example, AFRL has been developing a 6U size "Cubesat" that could be used as the basis for a spin-stabilized spacecraft.

## Conclusions

By providing a means to measure orientation with arcminute accuracy, the X-ray Star Scanner fills a key need in attitude sensing systems for CubeSats and microspacecraft, opening up new and exciting missions to CubeSat users. The development of the XSS is being conducted by CrossTrac Engineering through a NASA Phase I Small Business Innovative Research Grant under the supervision of the Jet Propulsion Laboratory.

#### References

<sup>1</sup>Hanson, J. E., "Principles of X-ray Navigation," Doctoral Dissertation, Stanford University, 1996,

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<sup>2</sup> Voges, W., et al. "The ROSAT All-Sky Survey Bright Source Catalogue." <u>Astronomy and Astrophysics</u>. August 13, 1999.