Performance of the Microwave Anisotropy Probe AST-201 Star Trackers

Roelof van Bezooijen, AST Chief Engineer
Lockheed Martin Missiles and Space Advanced Technology Center
Palo Alto, CA 94304 USA

David K. Ward, Systems Engineering Branch
NASA Goddard Space Flight Center
Greenbelt, MD 20771 USA

The Microwave Anisotropy Probe (MAP) is a MIDEX mission that was launched on June 30, 2001 to create a full-sky map of the cosmic microwave background. Among the derived requirements of the attitude control system was attitude determination of 1.3 arcminutes, RSS of all three axes. Additionally, the full-sky scan strategy demanded the attitude determination requirement be met while the spacecraft was spinning at 2.78°/second. Finally, the Instrument's temperature sensitivity requirement of 20 microKelvin dictated an L2 orbit for MAP, escaping the potential magnetic and thermal contamination from Earth. In order to meet the attitude determination requirement while spinning, in a package that would survive MAP's passage through the Van Allen radiation belts, MAP relied on two modified Lockheed Martin AST-201 star trackers.

The AST-201 employs an 8-element radiation hardened lens assembly to focus an 8.8° × 8.8° image on a 1024 × 512 LM Fairchild Charge-Coupled Device (CCD). The digitized CCD image is internally processed to combine bright objects into potential stars (called "blobs") that are then ranked by visual magnitude. The 50 brightest blobs are used as potential guide stars in an efficient Lockheed Martin star identification algorithm that outputs a three-axis attitude represented by a quaternion. This quaternion output capability removed the need for a star identification algorithm in the spacecraft processor, and significantly simplified the attitude initialization algorithm, since the star tracker could acquire its own attitude without the benefit of *a priori* information.

In addition to the core capability described above, the MAP star trackers were also modified to meet specific mission requirements. A CCD-shift algorithm called Time Delayed Integration (TDI) was included in each star tracker to allow the trackers to perform while spinning up to 3°/second. TDI eliminates image streaking at rate (and the resulting poor signal-to-noise ratio) by shifting the integrated signal across the CCD at the same rate the star image moves across the field of view. Since the MAP mission operations resulted in spin rates between 0 and 2.78°/second, an autonomous TDI capability was developed that performed a series of acquisitions at different TDI rates to determine its correct value, then continuously calculated the rate based on frame-to-frame comparisons of output attitudes. In order to provide some radiation effect filtering during MAP's three to five phasing loop passes through the Van Allen belts, a simple pixel filtering scheme was implemented, rather than using a more complex, but more robust windowing algorithm. Finally, the trackers' 1553 data interface was modified to provide an AS1773 fiber optic data interface, as is used elsewhere on MAP.

In this paper, some effort will be made to describe the ground testing that was accomplished on the MAP trackers. These tests included Night Sky Tests that verified the "Lost in Space" attitude determination algorithm and predicted TDI performance, as well as a laser-imaging test that determined the image stability for each tracker. The test descriptions will include not only tests that were used to determine the attitude performance of the tracker, but also tests that were developed to verify continued functionality of TDI shifting and the attitude determination process once the trackers were integrated onto the spacecraft. An internal calculation of each tracker's accuracy will be described, and its relevance in measuring the continued performance of the tracker through ground testing. Finally, the retest plan that was used when the trackers were reworked to correct a generic part problem at NASA GSFC will be described, including the limitations of the plan and the philosophy behind the plan.

The ground test data will then be compared with flight results gleaned from the first six months of MAP's mission. An initial look at star tracker data while inertially fixed will be compared with data while the spacecraft was spinning at the fast scan rate to determine if there is any degradation in performance. The ground calibrations for effective focal length and star brightness will be compared against flight data to determine their stability through launch. Trends in image quality data such as spatial noise levels and average background noise will be compared from launch to the present to determine if there has been any degradation that might impact the image quality or lifetime of either tracker.

The three phasing loop trajectory used by MAP to reach L2 will also provide quality data regarding the performance of the trackers in the presence of energized protons, as they were encountered as MAP passed through the Van Allen radiation belts. Analysis predicted loss of track due to proton interference for altitudes lower than 1.1 Earth radius (7,000 km, also known as L-shell 2.1) with proton effects appearing closer to an altitude of 12,800 km (L-shell 3) and the worst effects seen at an altitude of 2200 km. The MAP trajectory resulted in each one of the perigees dropping below the "loss of track" altitude: P1 was at 3098 km, P2 was at 2954 km, and P3 was at 4741 km. In the first two cases, the trackers did lose track, though the altitude at which tracking was lost was lower than previously expected. During the final perigee pass, both trackers managed to stay in track throughout. Image quality data will be reviewed to show the effect of energized protons in each case, and the potential benefit of adding the pixel filtering or windowing scheme will be compared.

Another feature of the phasing loop trajectory was the amount of time spent with the Moon near the nominal scan pattern of the star trackers if the spacecraft were in its full-sky mapping mode. This provided an opportunity to check the effect of stray light on each tracker as they were spinning past the Moon, and also provided an operational challenge that eventually required temporary modifications to the scan pattern. Data from different Moon crossings will be reviewed to show the effect of the stray light on functionality and performance.

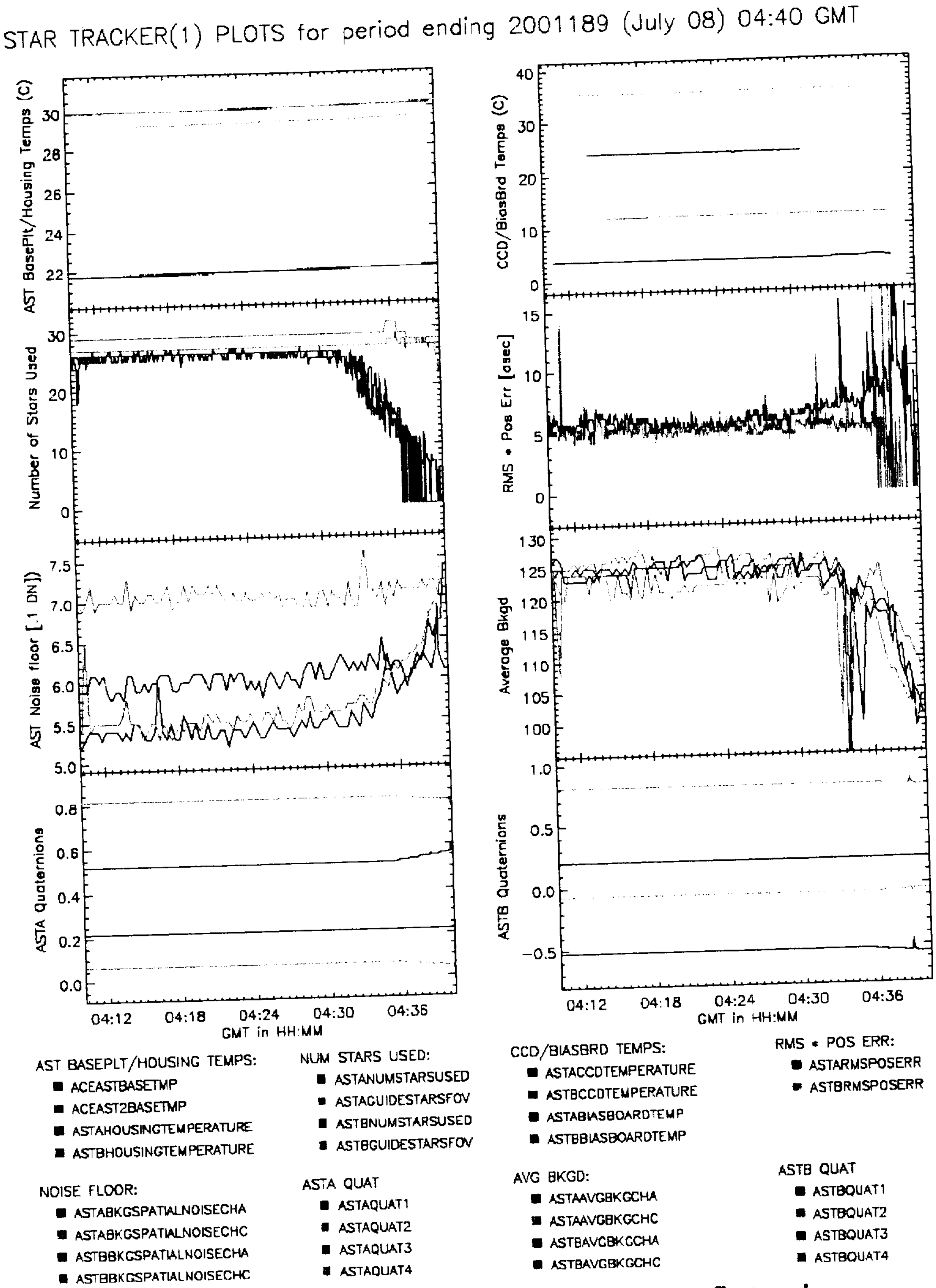

Figure 1: Star tracker data for period just prior to first perigee

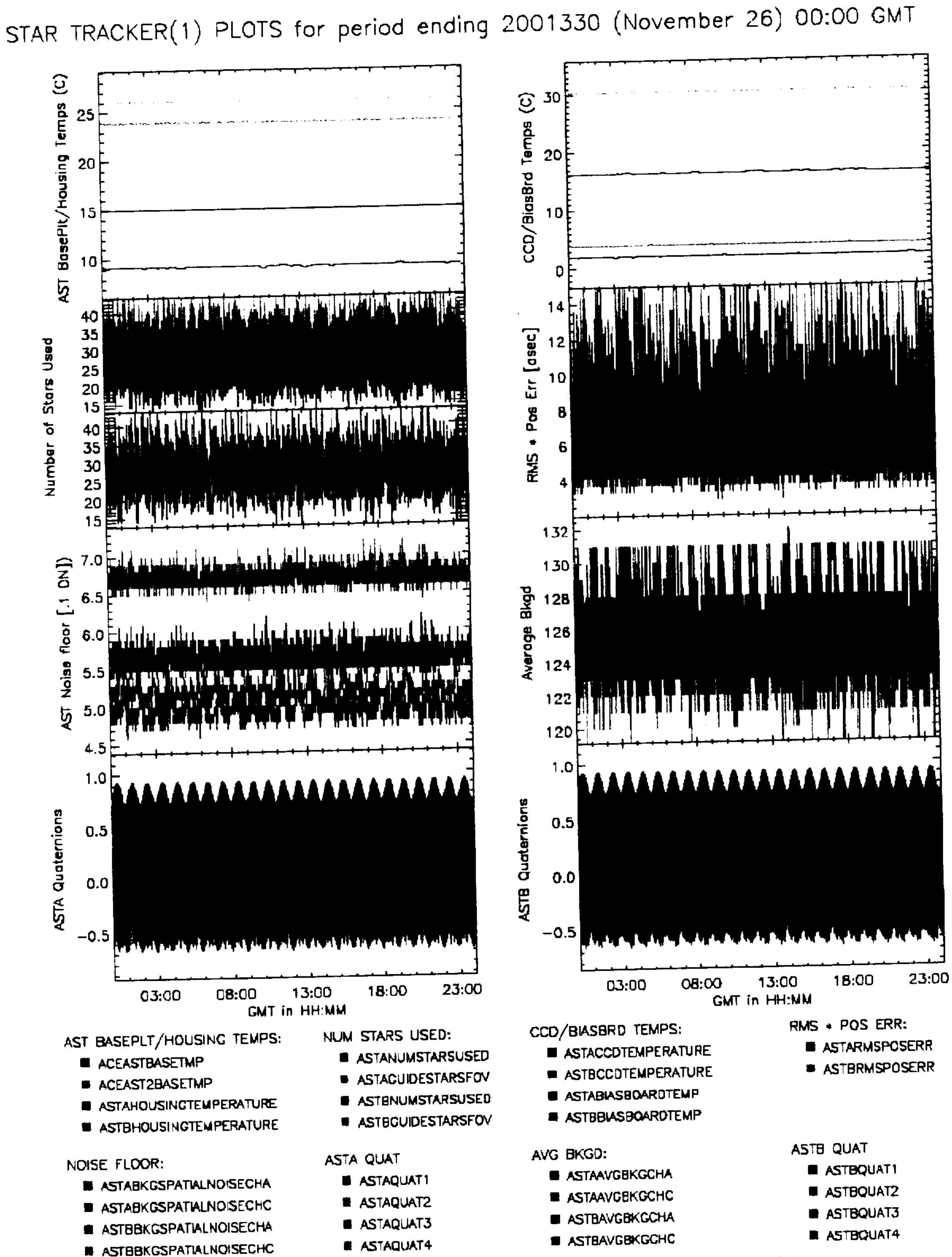

Figure 2: Nominal star tracker data for day 2001-329