Gravity Probe B Timing System and Roll Phase Determination

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GP-B Roll Phase

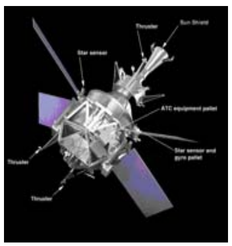
The GP-B satellite is controlled to roll with a period of 77.5 sec about an axis along the direction to the guide star.

- Disturbance torques fixed to the body of the satellite are averaged out.
- Gyroscope readout noise is reduced.

The roll phase is required in the data analysis to separate the drifts of the gyroscope spin axes in the orbital plane and perpendicular to the orbital plane.

The roll phase is determined on the ground to high accuracy with telemetry data from star trackers.

Roll Phase Instrumentation



There are two star trackers onboard the GP-B satellite.

- Field-of-view: 8°x8°
- Boresight axes are 50° and 60° away from the satellite roll axis, out of phase by 180°

Two Attitude Reference Platforms (ARPs) are mounted on the graphite ring around the dewar of the satellite.

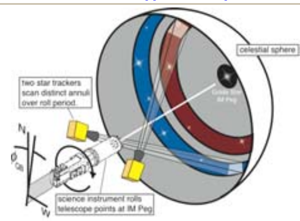
One control gyroscope package and one star tracker are mounted on each ARP

Close-loop control of the roll phase is implemented with 16 proportional cold gas thrusters by the Attitude and Translation Control (ATC) system.

Determining Roll Phase

Objective of analysis:

- **Determine roll phase, referenced to true north, of Quartz Block relative to apparent star positions.**



Ideal roll phase: $\phi_{QB}(t) = \omega_{roll} t + \delta\phi_0,$

where $\omega_{roll} = 2\pi$ / 77.5 rad/sec and $\delta\phi_o$ is constant.

Deviations from ideal:

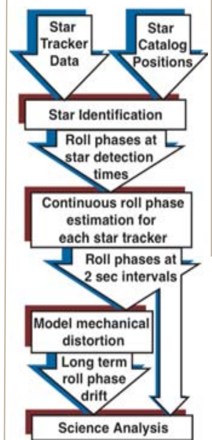
Operational (exactly known):

- **Computer reboots** change $\delta\phi_o$ to a different fixed value.
- **Onboard alignment matrix updates and sensor switching** change the reference positions of the roll phase sensors, and thereby change the meaning of commanded roll phase.

Disturbances (estimated from data):

- **Roll pointing errors** relative to commanded values.
- **Mechanical distortions** between sensors and quartz block.

Determining Roll Phase



Star tracker data includes:

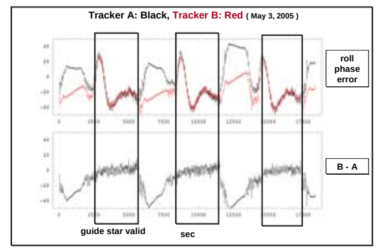
- Centroid positions on CCDs
- Star magnitude
- Time of centroid detection

Star Identification:

- Pair-wise pattern matching to catalog using high occupancy bins of histogram of angular separation, difference in angle to IM Peg, and magnitude difference.
- Typically ID 10-25 stars per roll period per tracker.

Estimation at 2 sec intervals:

- Star detection frequency dependent fit over several roll periods to a short term model including 2nd order polynomial, and up to 3 harmonics of roll frequency.
- Fit RMS consistent with instrument centroid accuracy (~7 arcsec)



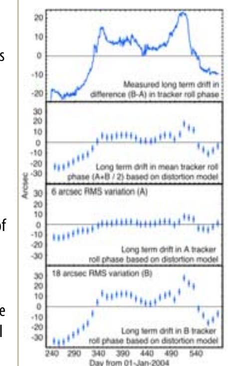
Determining Roll Phase

Long term distortions are estimated based on observed difference between the two sensors (A & B).

Sensors are attached to a common graphite ring

- Ring structure constrains the long term relationship between differential and common mode of sensors

A fit of differential mode distortion to thermal gradients determines the parameters of the model of ring compression and torsion.



Uncertainty in roll phase does not currently contribute significantly to GP-B experiment error.

- Contributions are ~ 3 x 10^{-5} of gyro misalignment

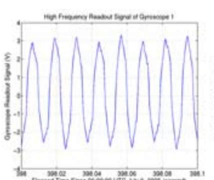
Additional sources of roll phase information are available for verification, including spin phase from high frequency gyro data (see below) and potentially, the gravity gradient signal in gyro suspension data.

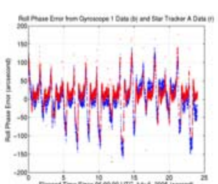
Roll Phase Determined from Gyroscope Data

Thermal distortion of the ARP was observed during the GP-B flight.

Roll phase error (deviation of roll phase from uniform roll) determined from the high frequency readout signals of the science gyroscopes is independent of the thermal distortion of the ARP.

Roll phase error determined from the science gyroscope data and the star tracker data shows good consistency.



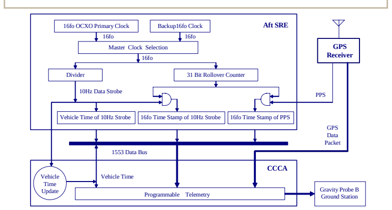


GP-B Timing System

The primary clock of GP-B is an oven-controlled crystal oscillator, which produces the 16.368 MHz master frequency, and is called the $16f_0$ clock.

The $16f_0$ clock and the 10 Hz data strobe, which is divided down from the $16f_0$ clock, provide clock signals to all GP-B components and synchronizes the data collection, transmission and processing.

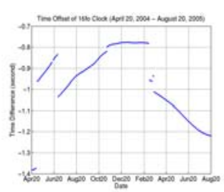
The sampled data of all GP-B science signals are stamped with the vehicle time, a counter of the 10 Hz data strobe.

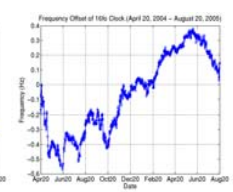


Time Conversion between Vehicle Time and UTC

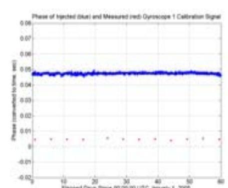
The Global Positioning System (GPS) receiver onboard the GP-B satellite supplies the Pulse-Per-Second (PPS) signal at integer seconds of Coordinated Universal Time (UTC).

The time conversion between the vehicle time and UTC is established in the ground processing of the telemetry timing data.

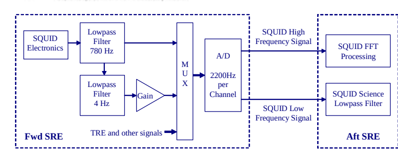




Effective Sample Time of Science Data



The time latency between the sample time of the science data and the stamped vehicle time and the time latency due to analog lowpass filters are compensated in the ground data processing.



Conclusions

The error of the roll phase determined on the ground is 7 arcsec (RMS). The peak-to-peak value of the roll phase error is less than 80 arcsec.

The error of time conversion between the vehicle time and UTC is less than 2×10^{-6} sec. The time latency between effective sample time of science data and the stamped vehicle time is verified to an accuracy of 1×10^{-3} sec in the ground tests.

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