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TITLE

DOPPLER AIDED ATTITUDE DETERMINATION FOR SPIN STABILIZED SPACECRAFT

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ABSTRACT

Spinning spacecraft with offset antennae present problems for Doppler-based orbit determination due to the presence of the spin signature in the tracking data. If not removed, the spin signature can alias into spacecraft state estimation or (if deweighted) increase the state covariance, as well as masking data signatures that are important, but much smaller than the spin signature. Removing the spin signature cures these problems, as well as helping attitude determination by finding the spin axis pointing direction. This paper describes the theory of spin signature removal and the results obtained during the Genesis and Contour missions, during which spin axis pointing measurement errors of 1 degree or less were achieved.

EXTENDED ABSTRACT

Spin signature

A spacecraft with antenna offset from its spinning axis makes a sinusoidal signature in the tracking data due to the antenna motion depicted in the Figure 1.

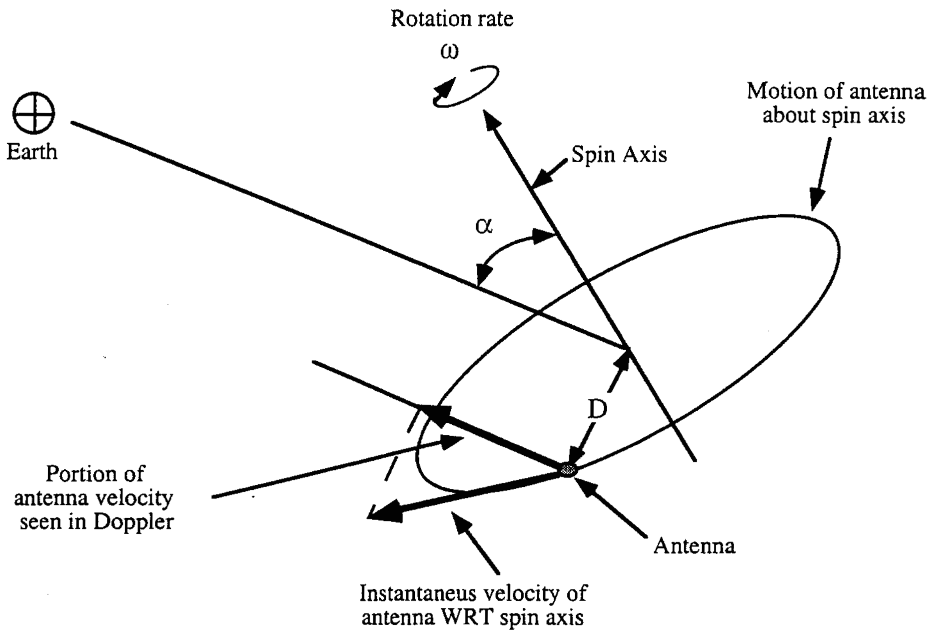

Figure 1: Antenna spin signature geometry

Assuming signatures caused by spacecraft motion relative to the center of the Earth, spacecraft motion relative to the ground tracking stations, and the constant bias caused by the antenna polarization can be removed by Orbit Determination (OD) processes, the *spin signature* can be simply expressed as:

$$F(t) = D\,\omega\,\sin\alpha\,\sin\omega(t-t_0) \quad (1)$$

where D = distance from the spin axis to the electric center of the antenna

ω = spacecraft spin rate

α = angle between the spin axis and S/C to Earth line (Earth look angle)

t_0 = reference time

For any spinning spacecraft ($\omega \neq 0$), if the antenna offset D is zero the signature F(t) is zero for all t. If the spin axis is pointed along the Earth line ($\alpha = 0$) again the signature F(t) is zero for all t.

The sinusoidal pattern will peak when the antenna crosses the intersection of the plane perpendicular to the spin axis and the plane perpendicular to the Earth line.

Solution for the spin signature

Solving for the spin signature should be part of the nominal OD process whenever possible. Without removing the spin signature, the Doppler data must be deweighted with a much larger value, and the included spin signature will be simply treated as an increase in data noise.

The procedures required for the spin signature solution are as follows:

• Measurement of the antenna-offset (D) from the spin axis before launch.

• Telemetry (onboard sensor reading) or real time tracking data for initial spacecraft spin rate (ω_0).

• Use ω_0 as *a priori* values for OD filter process and estimate ω, α based on the tracking data for the time span.

The last step will be repeated until the parameters can be estimated within the desired tolerance. From this process, the spin signature from the Doppler data will be removed and further OD processes will be used to estimate the trajectory. A by-product of this process is the Earth look angle, the angle between the spin axis orientation and S/C to Earth line. This can be used to solve for the inertial spin axis pointing direction, when combined with sun sensor and ephemeris data.

Using the Earth look angle for attitude determination

The Earth look angle α defines a cone where the spacecraft spin axis is pointing in inertial space. Combined with on board sun sensor reading, which defines another cone, two possible solutions can be obtained at the intersection of two cones.

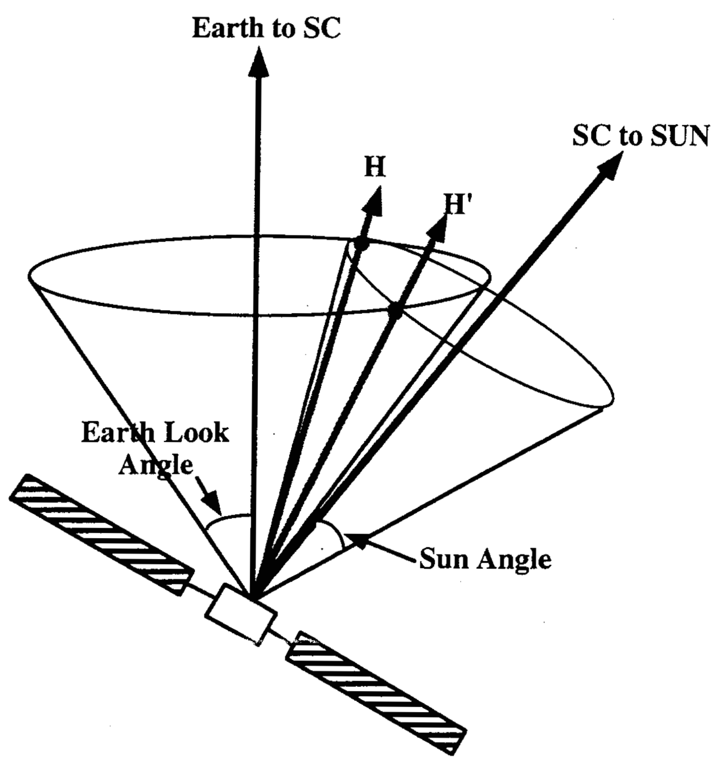

Figure 2: S/C spin axis pointing direction

In Figure 2., two possible solutions for the spin axis pointing vector are shown as **H** and **H′**. One solution will drift with time while the real solution will be the inertially stable one.

This method was used to aid the attitude determination for the Genesis and Contour spacecraft. This paper will show the sample cases of this application using Genesis and Contour tracking data.