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Title: GPS-LIKE TRACKING (GLT) OF GEOSYNCHRONOUS SATELLITES: ORBIT DETERMINATION RESULTS FOR INMARSAT AND TDRS

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The Global Positioning System (GPS) is emerging as the tracking system of choice for a variety of Earth orbiting missions. The most common application is for low-Earth orbit, where a spacecraft carrying a GPS flight receiver can autonomously determine its instantaneous position (and offset from GPS time) by observing a minimum of 4 GPS spacecraft simultaneously. Advanced variations on this technique exploit differential ground-based GPS measurements over long data arcs and in the presence of dynamic models to reduce systematic errors and enhance precision. It has recently been demonstrated that orbits for the Topex/Poseidon spacecraft can be determined to better than 3 cm (rms) in the radial component using this strategy [*Bertiger et al., 1994]*. This remarkable result can be attributed in large-part to the multi-directional observing geometry and continuous tracking afforded in iow Earth orbit by GPS. At higher altitudes, the visibility of the GPS spacecraft begins to degrade, and above the GPS constellation (altitude of 20,200 km) it becomes necessary to use a nadir-pointing antenna to sce any GPS spacecraft. For spacecraft in geosynchronous orbit, the signals from oniy 1 –2 GPS spacecraft are typically visible and complications associated with the long propagation distances and limb-grazing geometries are exacerbated. Wc have investigated an alternative to this method wherein GPS-compatible radiometric signals from the geosynchronous orbiter are tracked from ground stations. The resulting observations are used to compute the orbit for the geosynchronous satellite in much the same way that the orbits for the GPS spacecraft are determined (Figure 1). in the ideal realization of this technique-- hereinafter called GPS-like tracking (GLT)—the signals from the geosynchronous and GPS spacecraft are tracked simultaneously using enhanced GPS ground receivers. In this way, the GPS timing and range signals can be exploited to precisely determine station coordinates and media delays and to provide sub-ns synchronization of the clocks at widely dispersed ground stations. We have undertaken two experiments of this GLT concept, each demonstrating different aspects of the system.

In the first experiment, we use data from the Inmarsat-2 AOR-West geostationary satellite, which has been equipped with a transponder designed to broadcast a pseudo-GPS signal. This transponder capability is an element of the planned Inmarsat Geostationary Overlay (I GO) system, which will be used to disseminate integrity data and differential corrections for the FAA's Wide Area Augmentation System (WAAS) as part of an augmented positioning service. Use of this broadcast service will require accurate knowledge of the Inmarsat satellite positions. Orbit accuracies on the order of 1 m are desirable and would support nanosecond-level precise time transfer and dissemination over the Inmarsat area of coverage. NAVSYS Corp. has built a ground station test bed to generate the pseudo-GPS signal via the IGO transponder [*Kelecy et* al., 1994], and has tested this system during two separate demonstrations (Dec. 1993 — Jan. 1994, and Oct. — Dec. 1994). Two monitoring receivers were set up at the National Institute of Standards in Boulder, CO, and at the COMSAT Earth station in Southbury, CT, to measure a C/A code pseudorange signal modulated on the L-band downlink from AOR-West. We describe ephemeris computations for the AOR-West spacecraft based on the precise processing of these data using the Jet Propulsion Laboratory's (JPL) GIPSY/Oasis II software package. Consistency checks based cm the agreement of overlapping orbit ephemerides from the first demonstration suggest that 10 m orbit accuracies are achievable with the current data set (Figure 2). Covariance analysis are used to support the conclusion that future enhancements will permit 1-m level orbit accuracies.

We also describe results from an experiment in which NASA Tracking and Data Relay Satellites (TDRS) and GPS spacecraft were tracked simultaneously from a small (3 station) ground network in the western U. S. [*Haines et al.*, 1994]. This experiment contrasts with the IGO demonstration because no modifications of the existing TDRS space-to-ground link (SGL) were possible. The transponders on board the current TDRS spacecraft broadcast at Ku-band (14 GHz) and illuminate only a limited region surrounding the TDRS Earth station at White Sands, New Mexico. For our demonstration, the phase of the SGL carrier was tracked together with GPS L-band signals in enhanced geodetic-quality TurboRogue GPS receivers (Figure 3). The enhanced receivers simultaneously measured and recorded both the TDRS SGL and the GPS carrier phases with sub-mm precision, enabling subsequent precise TDRS orbit determination with differential GPS techniques. The precise GPS calibrations allowed the TDRS phase data to yield extremely precise measurements of the velocity of the spacecraft in the plane of the sky, even over the short baselines represented in our experiment. A small number of calibrated ranging points from routine operations at the TDRS Earth station were used to supplement the GLT measurements in order to improve determination of the TDRS longitude. Various tests performed on TDRS orbits derived from data collected during this demonstration-- -including comparisons with the operational precise orbit generated by NASA Goddard Space Flight Center (Figure 4)-—provide evidence that the TDRS orbits have been determined to better than 25 m with the GLT technique. improvements to enable 10 m accuracy will also be discussed.

Drawing on the results, as well as experiences with automated Topex/Poseidon and GPS orbit determination at JPL, we discuss prospects for using GLT to operationally collect and process geosynchronous data for orbit determination in a very low cost, highly automated system. The high potential for inexpensive, automated high-performance tracking should render the GLT technique attractive to designers of NASA, military and commercial systems used for orbit determination of satellites at geosynchronous as well as other altitudes.

Bertiger *et al.*, "*GPS* Precise Tracking Of Topex/Poseidon: Results and implications," J. Geophys. Res., Topex/Poseidon Special issue, Vol. 99, Dec. 15, 1994.

Kelecy, T., A. Brown, W. Bertiger, S. C. Wu and S. M. Lichten, "Orbit and Ranging Analysis of the Inmarsat AOR-West Geostationary Satellite", Proceedings of the ION 50th Annual Meeting, Colorado Springs, CO, June, 1994.

Haines *et al.*, A novel use of GPS for determining the orbit of a geosynchronous satellite: The TDRS/GPS tracking demonstration, Proceedings of the ION- GPS 94 Intl. Tech. Meeting, Salt Lake City, Utah, September, 1994.

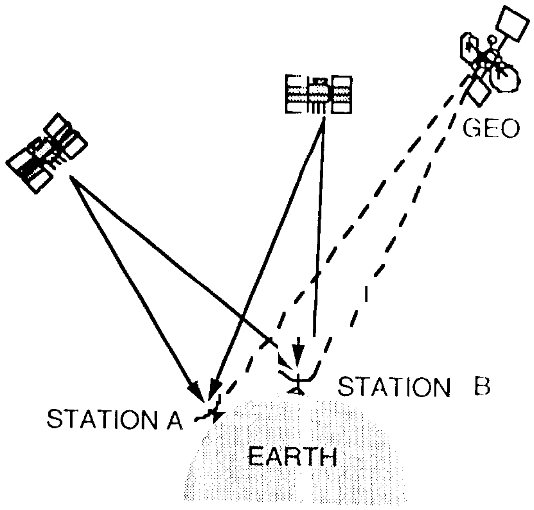

Fig 1. Differential GPS-like tracking (GLT) applied to geosynchronous orbiter. Four simultaneous observations of GPS carrier phase and pseudorange enable removal of transmitter and receiver clock offsets. After tracking for 12–24 hours, the GPS orbits can be determined to a few tens of centimeters. In GLT, the carrier phase of the high-Earth orbiter is also included and its orbit similarly estimated,

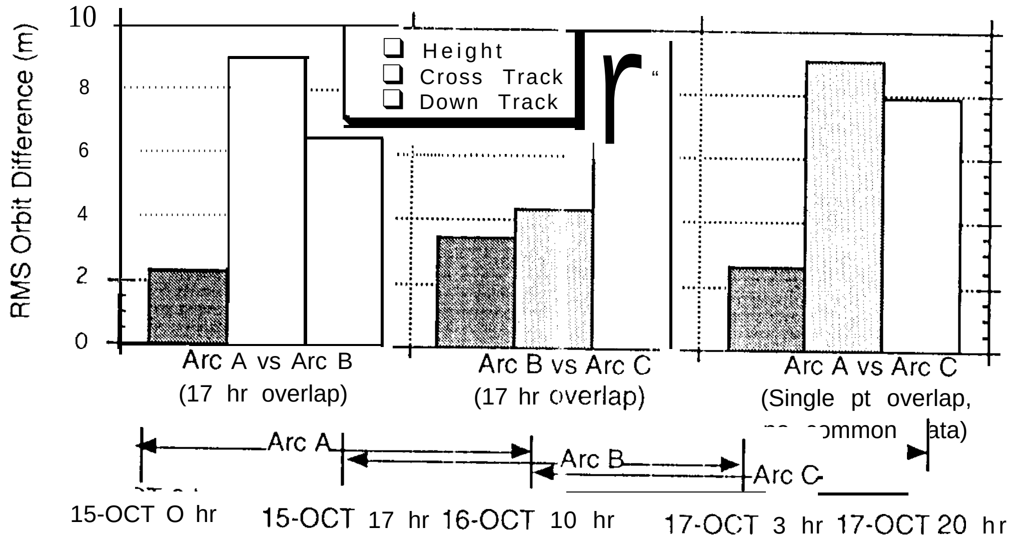

Fig 2. Inmarsat AOR-West orbit difference statistics for 34 bout orbit solution arcs overlapping by 17 hours. The orbits were determined with the GIPSY/OASIS II software at JPL using pseudo-GPS data collected by the NAVSYS Corp. ground receivers in Boulder, CO and Southbury, CT.

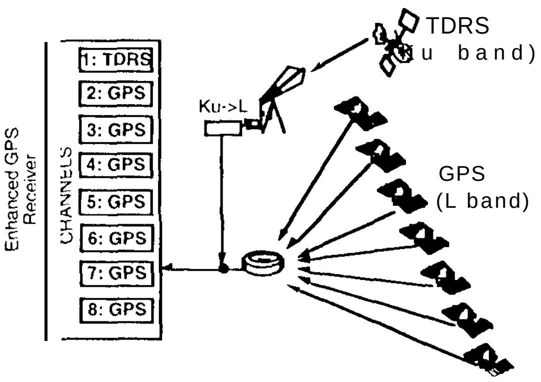

Fig 3. Schematic for the GPS ground receiver enhanced to simultaneously track TDRS along with GPS satellites. For the the TDRS space-to-ground link, which is at 14 GHz, a small separate antenna with down converter was added.

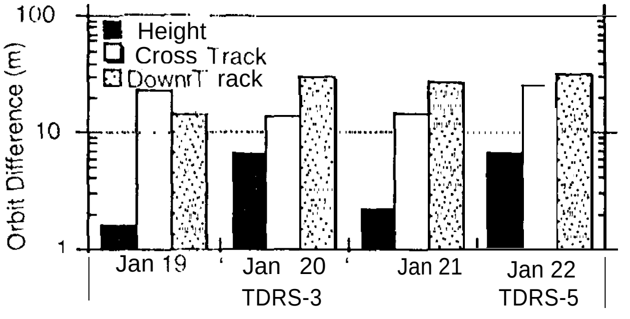

Fig 4. Bar graph summarizing RMS TDRS orbit differences (this study vs. Goddard operational precise orbit), The first three solutions correspond to TDRS-3 and the last to TDRS-5. The arcs vary between 18 and 2(l hours in length, The largest excursion over the entire set of comparisons is 52 m.