JPL VLBI Analysis Center Report for 2007

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Abstract

This report describes the activities of the JPL VLBI analysis center for the year 2007. We continue to do celestial reference frame, terrestrial reference frame, earth orientation, and spacecraft navigation work using the VLBI technique. There are several areas of our work that are undergoing active development. In 2007, an important development was the effort to move earth orientation and reference frame work to Mark 5 recording and software correlation. Our international collaboration to build celestial frames at K (24 GHz) and Q-bands (43 GHz) has matured to near a part-per-billion accuracy as has our in-house work to build a reference at X/Ka-bands (8.4/32 GHz). We are also studying the use of arrays for spacecraft tracking.

1. General Information

The Jet Propulsion Laboratory (JPL) analysis center is located in Pasadena, California. Like the rest of JPL, the center is operated by the California Institute of Technology under contract to NASA. JPL has had a VLBI analysis group since about 1970. Our work is focussed on supporting spacecraft navigation. This includes several components:

1. Celestial Reference Frame (CRF) and Terrestrial Reference Frame (TRF) are efforts which provide infrastructure to support spacecraft navigation and Earth orientation measurements.
2. Time and Earth Motion Precision Observations (TEMPO) measures Earth orientation parameters based on single baseline semi-monthly measurements. These VLBI measurements are then combined with daily GPS measurements as well as other sources of Earth orientation information. The combined product is used to provide Earth orientation for spacecraft navigation use.
3. Delta differenced one-way range (ΔDOR) is a differential VLBI technique which measures the angle between a spacecraft and an angularly nearby extragalactic radio source. This technique thus complements the radial information from spacecraft doppler and range measurements by providing plane-of-sky information for the spacecraft trajectory.
3. ΔVLBI phase referencing using the VLBA to measure spacecraft positions.

2. Technical Capabilities

The JPL analysis center acquires its own data and supplements it with data from other centers. The data we acquire is taken using NASA's Deep Space Network (DSN).

1. Antennas: Most of our work uses 34m antennas located near Goldstone (California, USA), Madrid (Spain), and Tidbinbilla (Australia). These include the following Deep Space Stations (DSS): the "High Efficiency" subnet comprised of DSS 15, DSS 45, and DSS 65 (see Figure

1) which has been the most often used set of antennas for VLBI. More recently, we have been using the DSN's beam waveguide (BWG) antennas: DSS 13, DSS 24, DSS 25, DSS 26, DSS 34, DSS 54, and DSS 55. Less frequent use is made of the DSN's 70m network (DSS 14, DSS 43, DSS 63). Typical X-band system temperatures are 35K on the HEF antennas. The 70m and BWGs are about 20K. Antenna efficiencies are typically well above 50% at X-band.

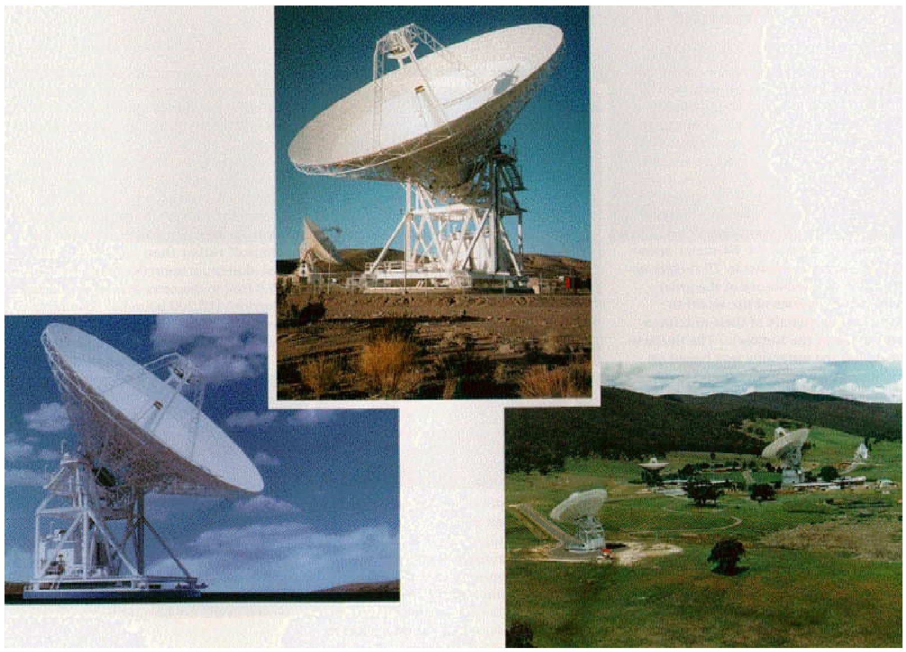

Figure 1. This figure shows the three high-efficiency antennas in the subnet: Goldstone is in the center; Robledo, Spain is on the lower left; and Tidbinbilla, Australia is on the lower right. These antennas were designed to have an optimum efficiency at X-band (8.4 GHz), which was to become the standard downlink frequency for solar-system exploration. An important secondary objective was to have a reasonable efficiency at Ka-band (32 GHz) thereby allowing for possible future use at the next highest band allocated for deep space communications. The subnet was completed in 1986 in time for the Voyager encounter with Uranus.

2. Data acquisition: The DSN sites have Mark 5A VLBI data acquisition systems. Mark IV tapes will still be supported for a few more months. In addition, we have JPL-unique systems called the VLBI Science Recorder (VSR) and the Wideband VSRs (WVSR) which have digital baseband converters and record directly to hard disk. The data is later transferred via network to JPL for correlation with our software correlator.
3. Correlators: The JPL BlockII VLBI correlator handles the TEMPO and CRF correlations of Mark IV format tapes while the SOFTC software correlator handles Mark 5A format recordings. The ΔDOR data from the VSR systems are also correlated using the SOFTC software correlator running on UNIX workstations. The VSRs and the software correlator have also been used for connected element interferometry tests of antenna arraying concepts.
4. Solution types: We run several different types of solutions. For ΔDOR spacecraft tracking we make narrow field ($\approx 10°$) differential solutions. The TEMPO solutions typically have a

highly constrained terrestrial (TRF) and celestial frame (CRF) as a foundation for estimating Earth orientation parameters. These reference frames are produced from global solutions which then provide the framework needed for use by TEMPO and ΔDOR.

3. Staff

Our staff are listed below with a brief indication of areas of concentration within the VLBI effort at JPL. Note that not all of the staff listed work on VLBI exclusively as our group is involved in a number of projects in addition to our VLBI work.

- Durgadas Bagri: antenna arraying for spacecraft tracking applications
- Jim Border: ΔDOR spacecraft tracking.
- Mike Heflin: CRF and TRF. Maintains MODEST analysis code.
- Chris Jacobs: S/X, K, Q, X/Ka CRFs, and TRF.
- Peter Kroger: ΔDOR spacecraft tracking.
- Gabor Lanyi: VLBA phase referencing, ΔDOR, WVR, K-Q CRF, and TRF.
- Steve Lowe: Software correlator, fringe fitting software.
- Walid Majid: ΔDOR, VLBA phase referencing.
- Chuck Naudet: WVR, Mark IV and Mark 5 support, and K-Q CRF.
- Lyle Skjerve: Field support of VLBI experiments at Goldstone.
- Ojars Sovers: S/X, K, Q, and X/Ka CRFs and TRF. Maintains MODEST analysis code.
- Alan Steppe: TEMPO and TRF.
- L.D. Zhang: S/X, K, and Q CRFs and TEMPO.

4. Current Status and Activities

In order to support the DSN's move to Ka-band (32 GHz), JPL is leading a collaboration with Goddard Space Flight Center, the U.S. Naval Observatory, National Radio Astronomical Observatory, and the Bordeaux Observatory to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) (Boboltz *et al*, 2007; Lanyi *et al*, 2008). In-house work to build an X/Ka-band CRF is also currently underway (Jacobs & Sovers, 2007).

The advanced Water Vapor Radiometer (A-WVR) continues to be used in research applications. This device can calibrate water vapor induced delays to a fractional stability of roughly a few parts in 10^{15} over time scales of 2,000 to 10,000 seconds and has demonstrated threefold reduction in VLBI residuals on time scales of 100 to 1000 seconds (Bar-Sever *et al*, 2007).

A number of activities are now underway to study the use of antenna arrays for VLBI-based spacecraft tracking including studies on the potential of the VLBA to make phase referencing observations of spacecraft positions (Bagri; Bagri *et al*; Majid & Bagri, 2007).

5. Future Plans

In the coming year we expect to move TEMPO and reference frame VLBI completely to Mark 5 recordings. Data rates will gradually be increased to 1 Gbps as resources allow. We plan to turn our proto-type Ka-band phase calibrator into a set of operational units. Our next generation fringe fitting program is also expected to come online in the next year. We anticipate refereed publications on our high frequency celestial reference frame work. On the spacecraft front, we plan to support a number of missions including the Mars Phoenix lander mission. Research will continue on techniques for using the VLBA and phase referencing VLBI for spacecraft tracking.

6. Acknowledgements

The work described here was in part performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

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