PRESENT AND FUTURE RADIO REFERENCE FRAMES

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ABSTRACT. Different but overlapping sets of extragalactic radio sources provide the reference frames for several purposes, notably Earth orientation and the terrestrial reference frame, spacecraft navigation, and astrophysical phase referencing. These reference frames have differing characteristics for numbers, spatial distribution and accuracy but have been unified up to now in the use of S/X band VLBI data and common observing stations. While the frequent observations for EOP are dominated by purpose-built geodetic stations, the majority of the global network stations have an astronomical focus or a major astronomical component. The ICRF has been the basis for assuring consistency among the various uses. In the future there is likely to be a specialization of reference frames driven by developments such as VLBI 2010, with instrumentation and network geometry optimized for EOP, and Ka-band spacecraft tracking. Higher frequency observations have the potential for improving the precision and stability of source positions. While the next realization of the ICRF will use S/X data, it will be important to relate other radio frames to the ICRF. The status of the second realization of the ICRF and some of the technological developments will be discussed.

1. THE PRESENT RADIO REFERENCE FRAMES

Radio-frequency reference frames are derived from VLBI observations. Currently the best realization of the ICRS is the ICRF, which was derived originally from simultaneous S-band and X-band VLBI data through 1995. Two extensions were made utilizing data through 2002 and increasing the number of sources in the catalogue to over 700 but retaining the original 212 defining sources, uncertainty floor of 250 microarcseconds and accuracy of the axes of 30 microarcseconds. The ICRF is the basis for realizations of the ICRS at other frequencies.

In practice, however, most ICRF defining sources are used less often than certain subsets of the ICRF catalogue and a large set linked to the ICRF. The most frequent VLBI observations utilizing the ICRF as a set of fixed fiducial objects are for monitoring Earth orientation parameters (twice a week for all five angles and daily for UT1) and for maintaining the terrestrial reference frame. For these purposes 150 sources with relatively high flux and compact structure have been used throughout the history of geodetic VLBI. These sources have the highest number and density of observations, have long time histories and thus dominate the VLBI data set. Recently the number of sources used regularly for geodesy was increased from 100 to over 200 and a few strong but unstable sources were deleted from the list. Simulations show that this change should improve the geodetic results.

For astronomical observations requiring a nearby source for phase referencing a much larger set is desirable. The positions of over 2000 sources were derived from the sessions of the VLBA Calibrator Survey (VCS). The astrometric quality is not as good as the ICRF since each source was observed at a single epoch, albeit with the VLBA, i.e, with many more stations than the usual astrometric network. The VCS sources were linked to the ICRF by including a number of ICRF sources in each session.

For spacecraft navigation in the solar system using differential VLBI a set of sources along the ecliptic is necessary, especially in the region of anticipated critical maneuvers. The Deep Space Network has been most active in observing such sources.

The fundamental requirements for developing a radio reference frame for general or specific purposes ht!

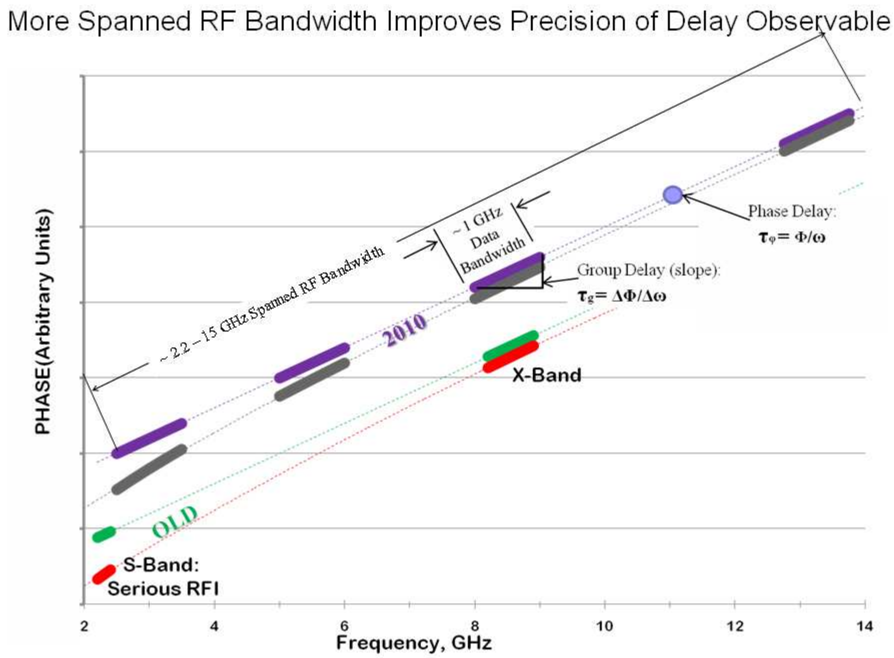

Figure 1: Schematic of the current S/X and the broadband systems

include simultaneous, dual-frequency observations to remove ionospheric effects, sufficient number, geographic distribution and sensitivity of stations, and sufficient sources over the sky and in particular regions as needed. The number of observing epochs and time span for the sources depend on the accuracy required but is also affected by the previous factors. The larger uncertainty for the VCS positions is still adequate for its purpose.

These applications have in the past all relied on dual S/X (2/8 GHz) VLBI observations. There are two developments that will lead to a proliferation of radio reference frames in the future, Ka-band space craft signals and the VLBI 2010 broadband system for geodesy. The benefits of Ka-band (32 GHz) for space craft telemetry are greater data capacity and smaller size. The DSN has already made X/Ka observations to develop a navigation catalogue but the number of X/Ka stations is very limited.

2. THE FUTURE RADIO REFERENCE FRAMES

The VLBI 2010 broadband concept is designed to meet ambitious geodetic and programmatic goals, mitigate worsening radio interference problems (especially severe at S-band) and replace ageing VLBI equipment. The goals include measurements accurate to 1 mm on a global scale, continuous measurements of Earth orientation parameters and station positions, quick data delivery and analysis, and low cost of construction and operation. The strategies include reducing random and systematic errors (particularly from the atmosphere), improving the number and distribution of stations (> 20 would be desirable), significantly increasing the number of observations in total and in a given time interval, and developing new observing strategies. Simulations show that a 24-station VLBI 2010 network should improve EOP by a factor of at least 5 over the current routine results, which are hindered by non-optimal network size and geometry and practical limitations on recording rate.

Figure 1 shows the schematic of the broadband system above and the current S/X system below. The current S/X system is in fact two discrete receivers at fixed frequencies. A group delay is determined from each band and the two group delays are combined to give an ionosphere-free observable. In the broadband system a single feed permits the sampling of multiple bands at arbitrary frequencies within the feed's bandwidth. The bands are placed to avoid interference. Each band is wider than the current S/X bandwidths and the overall spanned bandwidth is greater, so all bands are to be processed together to give an ionosphere-free phase delay with much higher precision than the group delay.

It should be noted that wide RF sampling and high rate recording are concomitant requirements. These are both needed to give sufficient sensitivity with 12-m antennas, which are smaller than the 20-30 m antennas most common in the geodetic network today. The reason for using smaller antennas is to reduce costs and for fast slewing.

The specific path under development by NASA and other organizations includes a fast, automated 12-m antenna, a broadband feed (2 - 12 GHz) and amplifiers, sampling in four, flexibly placed bands, and recording at 2 Gbps in a mode optimized for network data transmission and software correlation. Two proof-of-concept receivers and back ends have been built by NASA and installed on antennas at Westford, Massachusetts and Greenbelt, Maryland. The cryogenic receiver has a commercial, off-the-shelf broadband feed with dual linear polarization followed by broadband low noise amplifiers. Each of the four bands can be arbitrarily placed in the full RF range by a flexible up/down converter that acts as the local oscillator. Each band is split into 32 MHz channels and digitized by a digital back end (DBE) before being recorded at 2 Gbps on Mark5B+ recorders. These two systems have recorded data that have been successfully correlated.

There are two critical future steps for the proof-of-concept systems. The current feed has frequency-dependent phase center and beam pattern variations. A compact feed without these undesirable traits is under development at Chalmers University. A 12-m antenna to replace the 5-m antenna at Greenbelt has been ordered and is expected to be ready for testing by the end of 2009.

Other VLBI 2010 projects include the Twin Telescope at the Wettzell Fundamental Station, a new station at Auckland University of Technology, three new systems for Geoscience Australia at Hobart, Yaragadee and Katherine, and new stations in the Azores and Canary Islands.

In full operation the VLBI 2010 network would observe 200 sources continuously for EOP and station positions. Because of the broadband implementation the effective source positions will not be identical to the S/X positions. However, because of the density of observing and the optimized network distribution the data would provide a wealth of position and structure information about the sources used. Other sources could be observed by older, larger antennas that have been retrofitted with VLBI 2010 electronics.