

REPORT ITU-R SA.2132

**Telecommunication characteristics and requirements
for space VLBI systems**

(2008)

This Report describes the characteristics of the space VLBI systems. These characteristics form a technical basis for Recommendations related to space VLBI systems.

The contents of this Report were originally included in the Recommendation ITU-R SA.1344 – Preferred frequency bands and bandwidths for the transmission of space VLBI data, as an annex. That annex material has been removed from the Recommendation and is maintained in this Report. In preparing this Report, many revisions have been made to the material formerly in the Recommendation and the topics have been rearranged to improve clarity.

The Report includes a general description of the space VLBI systems and detailed descriptions of telemetry link for science data and of phase transfer link for time and frequency synchronization. Also included are the explicit equations for cross-correlation SNR and its degradation due to interference, required carrier frequencies and telemetry bandwidths, an interference criterion for the telemetry channel, effects of noise on the phase-transfer link, the characteristics of existing and planned space VLBI systems, and the characteristics of earth stations.

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1 Introduction

Very long baseline interferometry (VLBI) allows experimenters to observe radio sources with angular resolutions that cannot be approached by other methods. In addition, VLBI has other scientific and engineering uses. Observations of distant radio sources with two or more VLBI stations can be combined to determine the structure and positions of extra-galactic radio sources, to determine the geodynamical characteristics of the Earth, to study the Moon's libration and tidal response, to determine orientation of the solar system with respect to the extra-galactic inertial frame, to determine the vector separation between antenna sites, and to provide navigation and tracking of spacecraft.

2 Description of the space VLBI system

Space very long baseline interferometry (SVLBI) is a highly useful extension of very long baseline interferometry (VLBI), which in turn is a development from conventional radio interferometry. In all three cases, a specified bandwidth of cosmic or other radio emission is received simultaneously at two or more antennas that are distributed over distances much larger than the size of individual antennas. These bands, which can be described as time-varying spectra, are downconverted to a lower frequency so that they can be further amplified and then cross-correlated. In conventional interferometry this processing is done in real time. To preserve the amplitude and relative phases of the spectral components the downconversion has to be based upon a common local oscillator or frequency reference. The attraction of interferometry is that the angular resolution of the interferometer is related to the separations between the antennas rather than their physical size. However, there is a practical limit to how far antennas can be separated and still use real-time signal transfer, and that the largest conventional interferometers lack the angular resolution needed for the investigation of many types of cosmic radio source or determination of the position of distant space probes.

The development of ultrastable oscillators, accurate clocks and large-bandwidth data recording systems (using discs or magnetic tape) made it unnecessary to connect the antennas or use common local oscillator references, so the antennas could be moved further apart and the data taken after the experiment to a processing station where they could be synchronized and correlated, yielding a map of the source region. Antenna separations (interferometer baselines) of thousands of kilometres have been used successfully. However the diameter of the Earth sets a hard limit to the usable antenna spacings. Source visibility above the horizon in most cases limits the spacing even further.

Space very long baseline interferometry (SVLBI) removes this limitation by putting one of the interferometer antennas in space. Although in essence the process is still that of conventional ground-based VLBI there are some additional complications. Firstly the spacecraft carrying the spaceborne antenna element is moving at orbital velocity, and the motion has to be known quite accurately, and secondly the data have to be downlinked to a ground station for recording. Maintaining accurate time tagging of the data is much more complicated.

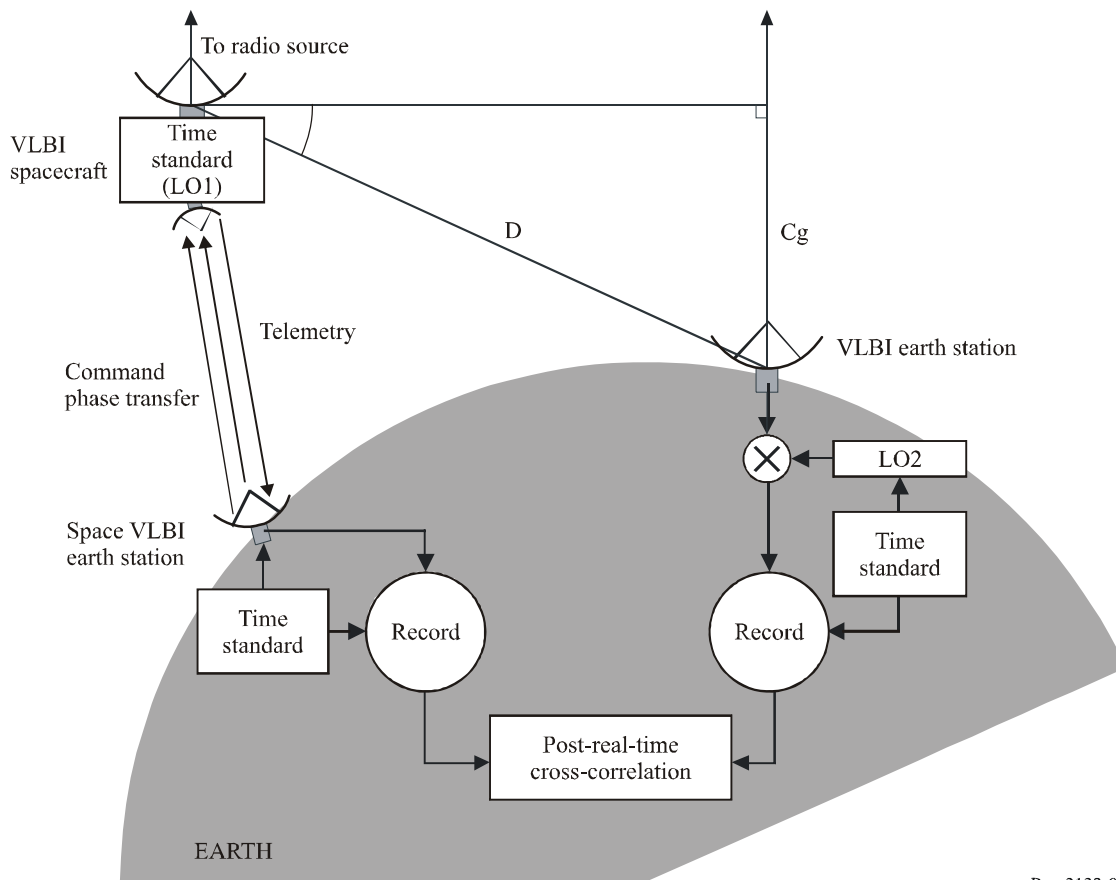
The configuration of a typical SVLBI experiment is shown in Fig. 1.

2.1 Telecommunication links for space VLBI

The telecommunication links of the space VLBI system are represented in Fig. 1 by the four dashed lines between the space VLBI spacecraft telecommunication antenna and the space VLBI earth station. A description of the radio links follows.

FIGURE 1

Outline of a typical space VLBI experiment, in which a spaceborne antenna is used in parallel with one or more VLBI observing stations on the ground



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2.1.1 Earth-to-space (E-s) telecommand link

This radio link is used for reliable transmission of telecommands required for operation and correction of possible spacecraft malfunctions.

2.1.2 E-s phase transfer link for time and frequency synchronization

In VLBI accurate knowledge of the time, the signal frequency, and the signal phase is needed for post-real-time cross-correlation. This requirement is met by using high-stability oscillators, often referred to as “atomic clocks,” at every station and also by utilizing the Global Positioning System (GPS).

At present an Earth-to-space phase-transfer link is used to impart the required time/phase reference to the spacecraft on-board clock and local oscillators. In the future the space VLBI spacecraft may have a space-qualified atomic clock. However, the distant space VLBI station may not be able to utilize the GPS system for time synchronization. Hence, the E-s phase transfer link will still be needed for time synchronization.

2.1.3 Space-to-Earth (s-E) telemetry link for science data

The space VLBI spacecraft observes the radio source over a selected bandwidth. This observed spectrum is transmitted to the space VLBI earth station using this s-E telemetry link for science data for recording and subsequent cross-correlation with the spectrum observed by the VLBI earth stations.

2.1.4 S-E phase transfer link

This radio link will be a coherent frequency translation of the Earth-to-space phase transfer link described above and will be used to calibrate the phase errors introduced in the Earth-to-space phase transfer link by different causes. This radio link may be dedicated to this phase transfer operation or may be combined with the s-E telemetry link for science data to transfer the observed spectra from the spacecraft as described in § 2.1.3.

3 Technical characteristics

A detailed characterization of the space VLBI telemetry link for science data and the phase-transfer link for time and frequency synchronization is given below.

In a space VLBI system, we need to consider two issues: firstly the observing system itself, which is similar to a terrestrial VLBI system except that at least one antenna is moving at a high and varying velocity compared with the rest of the network, and consequently establishing the velocity and position vectors is more complicated. This requires the transfer of timing and frequency standard signals between the ground and the spacecraft. Secondly, the data have to be transferred to the ground receiving station by a telemetry link. There could be quantization effects and also phase scintillation produced by the ionosphere.

The space VLBI spacecraft receives the radio source frequency spectrum contaminated with background and system noise in the observation bandwidth. This observed spectrum is transmitted to the space VLBI earth station where it is recorded and cross-correlated with the frequency spectrum observed at the earth station of the same radio source. The transmission of the observed spectrum from the space station to the earth station may be analogue or digital. In digital transmission, the observed analogue signal is first converted to a digital format and then transmitted to the space VLBI earth station for recording.

The transmission of a telemetry signal through space degrades the signal before it is detected at the earth station receiver. In digital transmissions, this degradation increases the errors in detecting the information bits. These degradations, thus, affect the final cross-correlation process of the space VLBI experiment by lowering the cross-correlation signal-to-noise ratio (SNR).

3.1 Telemetry link

3.1.1 Space VLBI cross correlation function

The basic observables in radio interferometry are the amplitude and relative phase of the cross-correlation of the two observed spectra. This cross-correlation process is usually performed in non-real time and may be expressed as:

$$R_{xy}(\tau_g) = \langle x(t) \cdot y(t - \tau_g) \rangle \quad (1)$$

where R_{xy} is the cross-correlation function, $\langle \rangle$ is the estimated mean for the observation over time, $x(t)$ and $y(t)$ are the recorded signals at sites 1 and 2, and τ_g is the wave front time delay.