# AO2 Proposer's Guide
# VLBI Space Observatory Programme

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**Abstract**

This guide provides the technical information necessary to write a proposal for scientific observations with the VLBI Space Observatory Programme (VSOP). Whereas the second VSOP Announcement of Opportunity (AO2) provides an overview of the VSOP mission and the proposal process, this guide provides technical details on many mission components and activities. These components include the VSOP spacecraft (HALCA), the ground radio telescopes, tracking stations, correlators and user support facilities of the VSOP mission. The guide also describes the observational capabilities of the VSOP mission, the VSOP scheduling process, HALCA calibration, data analysis tools, simulation software and how proposers can obtain help.

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# 1 VSOP Mission Description

The VLBI Space Observatory Programme (VSOP) is a project of the Japanese Institute of Space and Astronautical Science (ISAS) in close collaboration with the National Astronomical Observatory (NAO). In addition NASA and a number of organizations around the world are providing facilities and other support to the VSOP mission. The VSOP Science Operations Group (VSOG) is responsible for the day-to-day operation and management of the VSOP mission and is comprised of members from ISAS and NAO, with support from other individuals and agencies.

During its development HALCA was referred to as MUSES-B as it was the second in the series of ISAS's Mu Engineering satellites. However, after its successful launch on 12 February 1997 by the first launch of the M-V rocket, MUSES-B was renamed HALCA (Highly Advanced Laboratory for Communications and Astronomy). The HALCA spacecraft, as shown in Figure 1, has an 8 m diameter antenna and is expected to have a lifetime of 3-5 years. The mass and power budgets of the spacecraft are presented in Appendix C (Tables 17 and 18). HALCA is in a 6.3 hour orbit with an apogee height of 21,436 km (see §5 for more details on the orbit). The precession of the spacecraft's orbit allows good $(u,v)$ coverage to be obtained for all parts of the sky for at least some epochs during the mission lifetime. The apogee height produces baselines to ground radio telescopes up to three times longer than on the Earth, while the perigee height of 543 km is low enough to fill the aperture without an annular gap between ground-ground and ground-space baselines. Typically, an observation during General Observing Time (GOT) lasts between 7–14 hours, although various constraints result in the loss of ground-space VLBI data for some part of each observation.

As stated in the second VSOP Announcement of Opportunity it is not possible to apply for 22 GHz observations during the period covered by the second AO. Consequently this guide concentrates on the characteristics of the VSOP mission at 1.6 and 5 GHz.

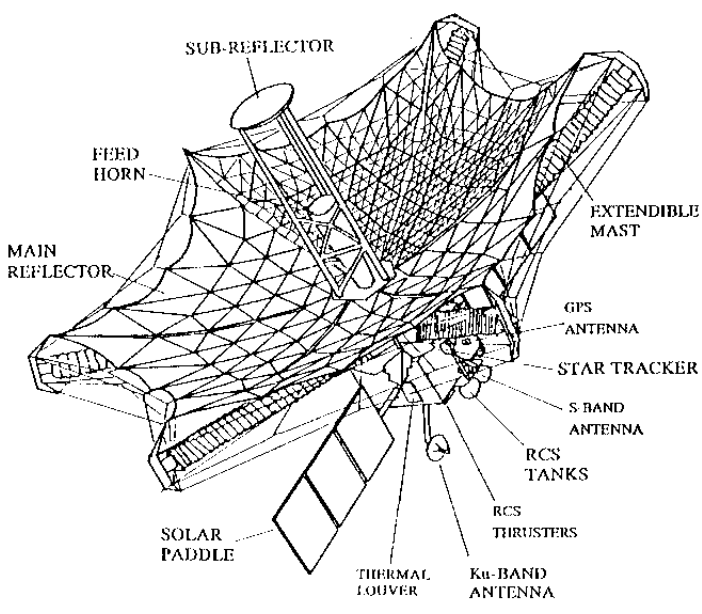


Figure 1: Diagram of the HALCA Spacecraft.

# 2 HALCA Antenna

The main HALCA antenna is a Cassegrain design with a three-waveband coaxial feed at the focus. Both the primary and secondary reflectors of the antenna were deployed in orbit. The primary reflector is composed of a thin mesh fixed in position by a set of cables attached to a support structure. The aperture has an area of 50.1 $m^2$, equivalent to an 8 m diameter reflector. A breakdown of the expected antenna gain is in Appendix C (Table 19) . Note the large spillover loss at 1.6 GHz due to the limited size of the sub-reflector.

# 3 HALCA Science Subsystem

The HALCA science subsystem, a block diagram of which is shown in Figure 2, processes the radio astronomy signal as follows. After a quarter wave plate combines the two orthogonal linear polarizations into LCP, the received radiation is sent down a coaxial cable in the case of the 1.6 GHz and 5 GHz bands, and a waveguide in the case of the 22 GHz to the Low Noise Amplifiers (LNAs). After launch it was discovered that there is a very high attenuation ($\approx$10 dB) between the feed and the 22 GHz LNA. This is the reason that the 22 GHz performance of HALCA is well below pre-launch expectations and why no 22 GHz observations may be proposed for General Observing Time during the period covered by the second VSOP AO. One theory for this high attenuation is that the waveguide was damaged during launch. At both 1.6 and 5 GHz the LNAs have receiver noise temperatures of $\approx$ 35–40 K and gains of $\approx$ 35–40 dB. Unlike the case for ground-based VLBI antennas, at 1.6 and 5 GHz there are both relatively large feed losses ($\approx$ -0.6 dB) and coaxial cable ($\approx$ -0.2 dB) losses between the feed and the LNAs, which are located on a plate that lies directly below the feed. Associated with these losses is a large contribution ($\approx$ 40–55 K) to the overall HALCA system temperature. The physical temperatures of the LNAs vary from $-24°$C to $+13°$C. The rest of the science subsystem is located on a solar panel side of the spacecraft main body, which is a good location for passive cooling of various components.

After the LNAs, the signals from each RF band are down-converted to IF, split into two paths, and sent to the IF switch. Two of the six input signals (two from each RF band), which in normal modes of operation will be from the same RF band, are then sent to two separate video converters. These two channels are referred to as channel A and channel B. Each video converter is an image rejection mixer (IRM) which converts the IF signal to baseband (0–32 MHz) as well as rejecting the lower side band image frequencies. The LO frequency for each of the two video converters can be chosen in integral MHz steps and are independently set.

After the video converters, the A and B channel signals each pass through either 16-MHz or 32-MHz low pass filters, depending on which HALCA observing mode has been selected. At this stage the A and B channel signal levels are sampled by square law detectors, the 12-bit digital outputs of which are sent to the main spacecraft computer, the data handling unit (DHU), to be subsequently sent down to the ground in the VLBI data headers. These power levels are used to determine the HALCA system temperature and to monitor the sampler power levels. After this point, the A and B channel signals are one- or two-bit digitized, QPSK encoded onto the 14.2 GHz Ku-downlink carrier, further amplified, and sent to the Ku-band link antenna for transmission to a tracking station on the ground. The data rate of the downlink signal is 128 Mbps. The steerable Ku-band link antenna has a diameter of 45.5 cm and is located on a boom to improve tracking station communication.

HALCA does not have an on-board hydrogen maser frequency standard, but receives its reference signal from the ground as a 15.3 GHz tone derived from a hydrogen maser at a tracking station. This 15.3 GHz tone is received by the same Ku-link antenna that is used to transmit the 14.2 GHz downlink. The 15.3 GHz tone is sent to the Ku-band receiver, whose function is to search for, detect, and convert this tone into the fundamental 50 MHz reference signal for the spacecraft. The measured phase residuals in the two-way link signal are used to correct the spacecraft clock and oscillators at the correlator.

HALCA system temperatures are measured using noise diodes (one for each frequency band). On/off power ratios and a model for the noise powers enables the system temperatures in both channels to be

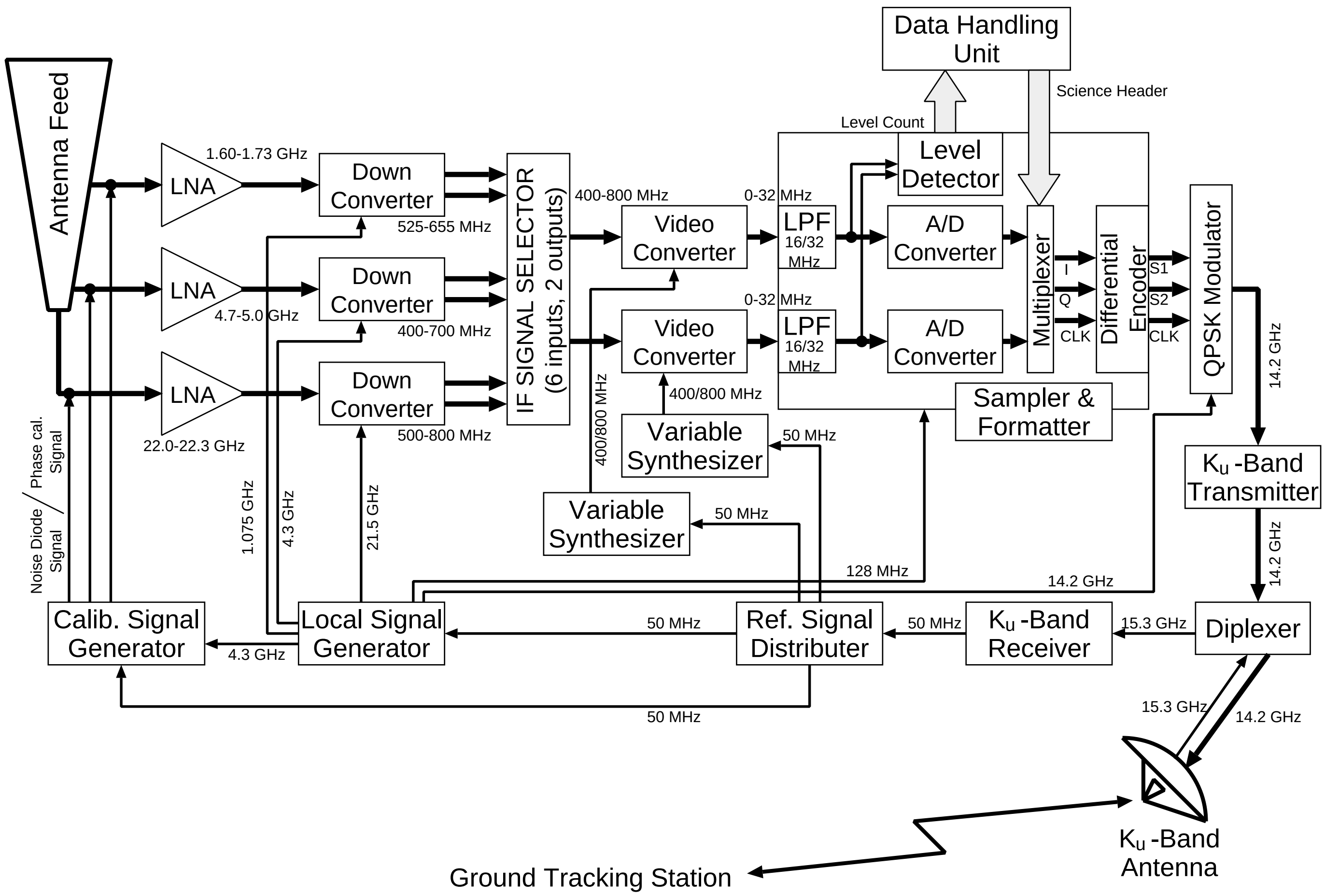


Figure 2: Diagram of the HALCA science subsystem.

determined. By default, phase calibration tones every MHz throughout the observing band are continuously switched on for continuum observations and switched off for spectral line observations. PIs can request on the VSOP proposal Cover Sheets that the tones be either switched on or off. Both the noise diode and phase calibration signals are injected through 25 dB couplers into the LNAs (see §12 for more details on HALCA data calibration). The phase calibration tones are extracted at the tracking stations.

The properties of the HALCA antenna and science subsystem are summarized in Table 1. The three VSOP observing modes are shown in Table 2. It is important to note that only one of the three observing modes is VLBA/MkIV/S2 compatible (see §8.1 for a discussion of the different VLBI recording systems that will be supporting VSOP observations). It is only this observing mode that can be used when HALCA is co-observing with non-Japanese ground radio telescopes.

Table 1: Properties of the HALCA Science Subsystem

| | Observing Band | |
|---|---|---|
| | 1.6 GHz (18 cm) | 5 GHz (6 cm) |
| Frequency Range (GHz)[1] | 1.60–1.73[2] | 4.7–5.0 |
| Polarization | LCP only | LCP only |
| Antenna Efficiency[3] | 24% | 34% |
| Antenna Sensitivity (mK $Jy^{-1}$) | 4.3 | 6.2 |
| System Temperature (K) | 75 | 95 |
| SEFD (Jy)[4] | 17400 | 15300 |

Notes:
1. The frequency range of each channel can be independently set such that the lower and upper frequencies of each channel are an integral number of MHz. The difference between the lower and upper frequencies of each channel must be equal to the channel bandwidth. Thus, for a 16 MHz channel, a frequency range of 1700–1716 MHz is okay, but both 1700.5-1716.5 MHz and 1700–1717 MHz are not.
2. Proposers who wish to observe the 1.72 GHz OH line should be aware that some ground radio telescopes, for example the VLBA, have difficulty supporting observations at 1.72 GHz due to the RFI environment.
3. The HALCA main antenna has a hexagonal shape which has a total area of 50.1 $m^2$ and is thus equivalent to a circular antenna of diameter 8.0 m. The antenna efficiencies quoted here are based on this area and include the effects of the feed and cable losses described in §3 and are thus not solely a measure of the quality of the antenna. These efficiency values are therefore somewhat lower than the traditionally defined aperture efficiency. Both aperture sensitivity and system temperature are measured at the noise source injection point, near the LNA input and *behind* the coaxial cables that join the feed to the LNAs. See §12 for details.
4. The system equivalent flux density (SEFD), also known as the system temperature in Jy, is the ratio of the system temperature in K to the antenna sensitivity in K $Jy^{-1}$.

Table 2: HALCA Observing Modes

| Mode properties | | | Recorder compatibility | |
|---|---|---|---|---|
| Number of channels | Bandwidth per channel | Sampling quantization | VLBA/MkIV/S2 compatible | VSOP terminal compatible |
| Two | 16 MHz | 2 bit | yes | yes |
| Two | 32 MHz | 1 bit | no | yes |
| One | 32 MHz | 2 bit | no | yes |