In-Orbit Checkout Plan for VSOP Radio Telescope

Version 3.0

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1. INTRODUCTION

This document contains a proposed plan for the in-orbit checkout (IOC) of the VSOP mission. The IOC plan presented herein assumes a VSOP launch date of January 20, 1997, and nominal deployment of the 8m antenna 11 days later, on January 31. An initial orbit with a 1,000-km perigee altitude, a 21,406-km apogee altitude, and a 31.3° inclination is assumed. The initial orbital elements $(a, e, i, \Omega, \omega, M)$ are taken to be (17,581 km, 0.5803, 31.3°, 186.0°, 100.7°, 0.0°), with a reference time of January 20, 1997, at 0.0 hours UTC. The resulting orbital period is 6.44 hours. The final selection of radio sources for various VLBI checks may differ from those suggested in this document because of uncertainties in the exact launch date and the final orbit, new information on source properties that will be acquired, and the actual rate of progress during IOC. Since there is still a large uncertainty in the performance of the M-V launch vehicle, the final orbital elements may differ significantly from those assumed here.

The goal of the IOC is to check out the end-to-end functioning of VSOP as a space radio telescope (SRT). Therefore, this plan includes the checkout of the spacecraft itself and the directly related ground systems. It is assumed that the individual ground systems themselves, and combinations of those ground systems (where possible), have been tested in an extensive period of pre-launch verification. The basic strategy of the plan is to make VLBI observations using ground radio telescopes (GRTs) on most Tuesdays and Thursdays. Although the detailed time scale for the individual tasks may differ considerably from that suggested in this plan, the chosen strategy provides excellent adaptibility for a range of possible circumstances during IOC. It is possible to reserve GRTs far in advance, then slide activities forward or backward in time by integer numbers of weeks without renegotiating the allocated GRT time.

It is *not* the primary function of the IOC to use valuable spacecraft time to check ground resources that can be tested without the spacecraft, such as compatibility of various GRTs and their VLBI systems with various correlators. In general, such resources should be checked independently of the VSOP activities, in order to minimize the load on the spacecraft and the VSOP Science Operations Group (VSOG). A preliminary description and schedule for the international mission operations aspects of pre-launch tests related to the SRT, which depends on the internal tests of the different mission elements, has been presented in "International Operations Test Plan for VSOP, Version 2.0," by J. Ulvestad and Y. Murata (December 19, 1995). This document is now badly out of date, but has never been updated or superseded. Completion of a program like that described in that test plan prior to launch would allow the IOC to concentrate on aspects of the mission that can only be checked when VSOP is in orbit, rather than detecting problems that could have been found prior to launch.

2. ELEMENTS OF THE SPACE RADIO TELESCOPE (SRT)

There are many elements that must work together to form the SRT. Recently, work has been done to provide more details of the IOC for a number of these elements; this document makes use of those newly developed details. We have divided the activities of the IOC into the following (somewhat arbitrary) categories:

(1) Pre-antenna Deployment
(2) Attitude and Orientation Control System (AOCS)
(3) Other Spacecraft Systems (SC)
(4) Standard Navigation System (NAV)
(5) Global Positioning System (GPS)
(6) Tracking System (TRK)
(7) Operations System (OPS)
(8) Calibration System (CAL)
(9) Correlation Systems (COR)
(10) Fringe Checks (FC)
(11) Imaging Tests (IM)
(12) Science Observations (SCI)

The following subsections describe each category of activities. Within each category, there are several subclasses of actions which are numbered for reference and described in the appropriate subsections.

2.1 Pre-Antenna Deployment

Details of the activities following launch, but prior to deployment of the 8m radio telescope, are beyond the scope of this document. Here we simply note several major items connected with the SRT. On days 2, 5, 7, and 9 of the mission, trajectory correction maneuvers (ΔV) are planned to raise the perigee to its final value. Following these ΔV maneuvers, the K_u-band telemetry antenna is deployed, and then the main 8m reflector is deployed. This deployment of the 8m radio telescope is scheduled for day 12, which would be January 31 if the spacecraft launches on January 20.

2.2 Attitude and Orientation Control System (AOCS)

The AOCS is separated from the rest of the spacecraft in the IOC plan because it dominates the other spacecraft systems in terms of the amount of time required during IOC. We divide it into nine activities, as developed by Kii-san. Only AOCS-1 through AOCS-7 are included explicitly in the current plan.

AOCS-1: Star tracker (STT) checks
AOCS-2: Checks of Coarse Sun Aspect Sensor and Sun Presence Sensor (CSAS and SPS)
AOCS-3: Measurement of drift and bias in the Inertial Reference Unit (IRU)
AOCS-4: Test of Safe-Hold mode (must precede any source observations)
AOCS-5: Measurement of alignment and scale factor of IRU
AOCS-6: Tests of maneuver capability
AOCS-7: Tests of dynamics of satellite under torques applied by reaction control system (RCS)
AOCS-8: Tests of 5-point boresight characteristics
AOCS-9: Tests of radial-scan mode

2.3 Other Spacecraft Systems (SC)

Tests of other spacecraft systems have been divided into nine activities. This division is rather arbitrary, and ignores many spacecraft systems such as the power systems, but concentrates on activities related to VLBI observations or to tests of other systems. The checkout of the onboard science system during IOC currently is poorly understood. More detailed evaluation of this aspect of spacecraft checkout could have a significant impact on the overall IOC plan.

SC-1: Checks of S-band telemetry system, including the different data rates for the telemetry recorder
SC-2: Tests of real-time control capability from Kagoshima Space Centre
SC-3: Tests of capability to operate spacecraft using Organized Commands (OC)
SC-4: Antenna check at 1.6 GHz, by pointing at radio sources to determine if a signal is seen
SC-5: Antenna check at 5 GHz, by pointing at radio sources
SC-6: Antenna check at 22 GHz, by pointing at radio sources
SC-7: Receiver check at 1.6 GHz, including operation of noise diode and phase-calibration tones, as well as calibration as a function of physical temperature
SC-8: Receiver check at 5 GHz, similar to SC-7
SC-9: Receiver check at 22 GHz, similar to SC-7

2.4 Standard Navigation System (NAV)

Here, the standard navigation system is taken to include measurements of range and range rate, as well as the spacecraft orbits derived from those data. After the K_u-band stations begin to come on line, continued exchange/verification of S-band data is not specified explicitly. GPS activities are described in Section 2.5.

NAV-1: S-band range and range rate, including data exchange between ISAS and JPL as well as orbit comparisons
NAV-2: Predicted orbit generation and delivery for Usuda 10m tracking station
NAV-3: Predicted orbit generation for Usuda, DSN, and Green Bank tracking stations, including comparisons of predictions by ISAS and JPL
NAV-4: K_u Doppler data gathering at Usuda, including data exchange from ISAS to JPL
NAV-5: K_u Doppler data gathering at Usuda, DSN, and Green Bank tracking stations, including data exchange between ISAS and JPL
NAV-6: Reconstructed orbit generation by ISAS and JPL, including comparison of results (includes NAV-5)
NAV-7: Development and modification of solar-pressure models for spacecraft (includes NAV-6)

2.5 Global Positioning System (GPS)

The IOC of the on-board GPS receiver is divided into seven activities, as supplied by Ichikawa-san.

GPS-1: Power up GPS unit and signal line
GPS-2: Test attitude data reception by GPS unit
GPS-3: Test commanding of GPS unit
GPS-4: Load Navstar satellite-selection sequence to GPS unit
GPS-5: Receive Navstar signals with GPS receiver
GPS-6: Calculate delta-range and pseudo-range from data gathered by GPS receiver
GPS-7: Test autonomous orbit estimation and propagation

2.6 Tracking System (TRK)

The IOC of the Usuda tracking system has been divided into several phases by Kawaguchi-san. Here, this division is used, and the DSN and Green Bank tracking systems are added. Kagoshima S-band tracking/commanding is assumed for virtually every day, but not noted explicitly after K_u-band stations begin to come on line.

TRK-1: Kagoshima S-band tracking only
TRK-2: DSN S-band tracking in addition to Kagoshima tracking
TRK-3: Usuda K_u-band 2-way link, with fixed uplink frequency
TRK-4: Usuda K_u-band 2-way link, with uplink frequency varied according to orbit predictions and with phase-calibration tone extraction at the station
TRK-5: Usuda, DSN, and Green Bank K_u-band 2-way link, with uplink frequency varied according to orbit predictions, and with phase-calibration tone extraction at the stations
TRK-6: Usuda 2-way link, with wideband data recorded on VSOP terminal
TRK-7: Usuda 2-way link, with wideband data recorded on VLBA recorder
TRK-8: Usuda 2-way link, with wideband data recorded on S2 tapes
TRK-9: DSN and Green Bank 2-way links, with wideband data recorded on VLBA tapes
TRK-10: DSN and Green Bank 2-way links, with wideband data recorded on S2 tapes

2.7 Operations System (OPS)

From the standpoint of the IOC, the Operations System is taken to consist of the various types of file exchange that are necessary for operation of tracking stations and correlators. We do not include activities such as provision of VEX files and log files for GRTs, since these can be checked completely independently of the VSOP IOC, and do not require the presence of a spacecraft in orbit.

OPS-1: SRT schedule files provided, including only spacecraft and Usuda tracking station operations, and used for those operations
OPS-2: SRT schedule files provided, including the spacecraft, all tracking stations, and GRTs
OPS-3: Delta-T files provided from Usuda tracking station
OPS-4: Delta-T files provided from all tracking stations, possibly via the VSOG
OPS-5: Data processing logs provided from tracking stations to VSOG
OPS-6: SRT logs provided from VSOG to correlators

2.8 Calibration System (CAL)

The calibration system includes the calibration of the SRT, along with the provision of appropriate calibration files,but does not include calibration of GRTs.

CAL-1: 1.6-GHz pointing and gain checks
CAL-2: 5-GHz pointing and gain checks
CAL-3: 22-GHz pointing and gain checks
CAL-4: Provision of phase-calibration tables in specified formats for use within AIPS
CAL-5: Provision of flag tables in specified formats for use within AIPS
CAL-6: Provision of gain tables in specified formats for use within AIPS
CAL-7: Polarization calibration

2.9 Correlation Systems (COR)

There are four different correlation systems that must be used to correlate spacecraft data during the early parts of the VSOP mission; each such system must be checked during IOC for its ability to correlate spacecraft data, using SRT log files, Delta-T files, and the reconstructed spacecraft orbit. As part of the VSOP correlator use, spacecraft data must be copied from S2 and VLBA tapes. Such copying for GRTs does not require VSOP, and is not included here. However, tape-copying for tracking station data, which is under control of somewhat different log input files than for GRTs, requires the VSOP spacecraft and is included.

COR-1: SRT data on VSOP-format tapes to the near-real-time correlator (NRT) in Japan
COR-2: SRT data on VSOP-format tapes to the VSOP correlator
COR-3: SRT data on S2-format tapes to the VSOP correlator
COR-4: SRT data on VLBA-format tapes to the VSOP correlator
COR-5: SRT data on VLBA-format tapes to the VLBA correlator
COR-6: SRT data on S2-format tapes to the Canadian correlator

2.10 Fringe Checks (FC)

Fringe checks will be done at all three frequencies, with a variety of telescope and correlator combinations. There are three different observing frequencies and four different correlators. It is desirable to check all correlators at all frequencies, since different levels of delay-model accuracy for the spacecraft are required for correlation at the different frequencies.

FC-1: 1.6-GHz fringe check using NRT correlator
FC-2: 1.6-GHz fringe check using VSOP correlator (usually includes FC-1
FC-3: 1.6-GHz fringe check using VLBA correlator
FC-4: 1.6-GHz fringe check using S2 correlator
FC-5: 5-GHz fringe check using NRT correlator
FC-6: 5-GHz fringe check using VSOP correlator (usually includes FC-5)
FC-7: 5-GHz fringe check using VLBA correlator
FC-8: 5-GHz fringe check using S2 correlator
FC-9: 22-GHz fringe check using NRT correlator
FC-10: 22-GHz fringe check using VSOP correlator (usually includes FC-9)
FC-11: 22-GHz fringe check using VLBA correlator
FC-12: 22-GHz fringe check using S2 correlator

2.11 Imaging Tests (IM)

Imaging tests will be done at all three frequencies, using a variety of telescopes. Here, we divide these tests according to the three frequencies. The division of telescopes among different arrays is discussed in Section 3. Note that in imaging tests that involve only the 10 VLBA telescopes, ground observations may be made in dual polarization for tests of the capability of the VSOP mission to do full-polarization imaging.

IM-1: 1.6-GHz imaging tests
IM-2: 5-GHz imaging tests
IM-3: 22-GHz imaging tests

2.12 Science Operations (SCI)

Science operations will progress from lowest to highest frequency, and will gradually increase from 1–2 days per week to as many as 6 days per week. Here, we divide the science operations according to frequency.

SCI-1: 1.6-GHz scientific observations
SCI-2: 5-GHz scientific observations
SCI-3: 22-GHz scientific observations

3. SPACE RADIO TELESCOPE CHECKOUT

This section describes the elements of the IOC that are directly related to the performance of VSOP as a space radio telescope. It does not include any description of items of type AOCS, NAV, GPS, and OPS (see Section 2 for definitions). Instead, it concentrates on the activities of the space radio telescope and other actions directly related to the supply of scientific data from the spacecraft to the ground. The time period for processing of the relevant data is considered in constructing the schedule, but details of data processing are not spelled out explicitly.

Different activities required for the IOC are listed and described below in time sequential order, from initial activities to those occurring at the end of the IOC period. In many cases, several activities will occur simultaneously, and the exact overlap of the elements of the checkout will be determined by the speed with which the different activities actually can be carried out.

3.1 Definition of Ground Telescope Arrays

Once the fringe-check stage is reached, a variety of arrays of GRTs may be useful under different circumstances. We have defined several arrays of GRTs that would be used for different purposes. The defined arrays are those which seem logical from the mission point of view, but in many cases it would be possible to substitute other telescopes in similar locations and with similar reliability in order to achieve the goals of the checkout observations. For each item, we give a list of telescopes, the identity of the correlator that might be used, and the general purpose for which the array can be used.

- AJ1: Usuda, Kashima, Parkes or ATCA, Hobart and/or Mopra, Tidbinbilla (1.6 GHz only); NRT or Mitaka or Canadian correlator
  –FC-1, FC-2, FC-4, FC-5, FC-6, FC-8, IM-1, IM-2

- AJ2: Kashima, Parkes or ATCA, Hobart and/or Mopra, Tidbinbilla, Nobeyama; NRT or Mitaka or Canadian correlator
  –FC-9, FC-10, FC-12, IM-3

- APT: AJ1 + Hart (Shanghai, Urumqi, Ceduna?); Mitaka or Canadian correlator
  –IM-1, IM-2 (**NOT** 22 GHz)

- J1: Usuda, Kashima; NRT or Mitaka or Canadian correlator
  –FC-1, FC-2, FC-4, FC-5, FC-6, FC-8

- J2: Nobeyama, Kashima; NRT or Mitaka or Canadian correlator
  –FC-9, FC-10, FC-12

- EVN-VLC: Effelsberg, Jodrell, Noto, Torun, Green Bank; VLBA correlator
  –telescopes with VLBA recorders, currently used only as part of EVN-LC

- EVN-MLC: Onsala, Effelsberg, Medicina, Westerbork, Madrid (1.6 GHz only); VLBA correlator
  –telescopes with Mrk IV recorders, currently used only as part of EVN-LC

- EVN-LC: EVN-VLC + EVN-MLC; VLBA correlator
  –FC-3, FC-7, IM-1, IM-2

- EVN-K: Onsala, Effelsberg, Noto, Madrid, Green Bank; VLBA correlator
  –FC-11, IM-3

- NRAO-1: 3–4 VLBA, Green Bank (Goldstone or phased VLA?); VLBA correlator
  –FC-3, FC-7, FC-11, IM-1, IM-2, IM-3

- NRAO-2: VLBA, Green Bank (VLA?); VLBA correlator
  –IM-1, IM-2, IM-3

- VLBA: 10 VLBA telescopes only; VLBA correlator
  –IM-1, IM-2, IM-3

- US-S2: Arecibo + Green Bank; Usuda or Mitaka correlator
  – FC-2, FC-4, FC-6, FC-8

- NEVN-LC: NRAO-2 + EVN-LC; VLBA correlator
  –IM-1, IM-2

- NEVN-K: NRAO-2 + EVN-K; VLBA correlator
  –IM-3

3.2 Antenna Checks (SC-4, SC-5, SC-6)

The first telescope-related activity after antenna deployment will be a preliminary measurement of the antenna performance. This measurement will be made to confirm complete deployment of the 8m antenna and to provide a preliminary measurement of antenna gain. It should be carried out as soon as possible after the AOCS has been checked out enough to permit pointing at a radio source (after the first tests to calibrate the IRU, AOCS-5). Because the pointing at high frequencies will be quite uncertain at this stage, the check will concentrate on the proper performance of the 8m antenna at 1.6 GHz. The 1.6-GHz performance will be tested by observation of strong continuum and OH maser sources. These first antenna checks should be made with real-time monitoring, while the VSOP spacecraft can be viewed from Kagoshima.

Since the first antenna tests will be performed in early February, the Sun will be near 21^h right ascension, so the ideal sources will be at high (positive or negative) declination or near 9^h right ascension. Tau-A, at right ascension 5.5^h can be used. The best OH maser source is Orion-KL; many of the other strong OH sources are too close to the Sun. (Note also that the line frequency will shift substantially during the orbit, which may complicate the data analysis.)

A crude check that the antenna and the signal path through the spacecraft are working properly would be to point the antenna at the Moon very soon after the spacecraft Safe-Hold test (AOCS-4) is complete. This does not require very accurate pointing, since the Moon is $0.5°$ in size. It would contribute about 100 K of antenna temperature at 1.6 GHz, and 300 K at both 5 and 22 GHz. Further checkout at 5 GHz and 22 GHz will occur later during IOC.

3.3 Spacecraft K_u Link Checks (TRK-3)

When VSOP is visible from Japan, the K_u-band (15-GHz) spacecraft link must first be established using the Usuda 10m station, with a constant frequency uplink. This activity is intended primarily as a test of the spacecraft systems, and not the ground tracking station. Provided that the K_u-band equipment on-board VSOP already has been verified, the establishment of the link should take place within a few days. When the spacecraft is not visible from Usuda, the primary activity will be checkout of spacecraft systems, particularly the AOCS.

K_u-band links to the U.S. tracking stations should occur only on a non-interference basis, meaning both no interference with spacecraft checkout and no additional workload imposed on the VSOG members in Japan. If there is some problem establishing the K_u link to Usuda after several days, establishment of the link to one or two U.S. stations must become a very high priority. The best stations to use in this case probably will be Goldstone and Green Bank, because of the ready availability of personnel for data analysis and troubleshooting.

3.4 1.6-GHz Pointing Analysis (CAL-1)

After the most important spacecraft checks have been made and the K_u-band link to Usuda has been established, the next activity will be a more thorough analysis of the pointing and gain of the 8m antenna at 1.6 GHz. If possible, the 8m antenna should observe several sources at 1.6 GHz and a variety of Sun angles. (Predictions are that the effects of differing Sun angle should be negligible at 1.6 GHz, but these predictions need to be confirmed in orbit.) The tradeoffs of using OH maser sources *vs.* continuum sources remain to be determined, and may depend on what is learned from the initial antenna check and the first pointing checks.

The first pointing observations will take place while the spacecraft is being tracked using the 10m antenna at Usuda. Data will be downlinked at K_u band and analyzed using the autocorrelator at Usuda. It is hoped that new pointing offsets can be uplinked during the same tracking session, and the new offsets checked immediately. Therefore, these observations should take place during long view periods for Usuda. Some observations may later be made when used when the spacecraft is out of the view of Usuda, with S-band telemetry used for the pointing analysis. In the early stages of IOC, a gain measurement with an accuracy of 10% and a pointing model good to better than 10% of the beam width should suffice. These will be refined in parallel with other activities.

3.5 K_u Link Checks to all Stations (TRK-4, TRK-5, TRK-6, TRK-9)

Concurrently with the 1.6-GHz pointing efforts, a K_u-band link should be established to Usuda and all U.S. tracking stations, with the uplink frequency varied as determined from a predicted orbit. All stations should be illuminated at K_u band as soon as possible, but the VSOG must determine the priorities that they use in data analysis, and should emphasize the analyses that are the most critical for proceeding to the subsequent IOC activities as quickly as possible.

Before K_u-band links are attempted using the DSN stations, it will be very useful to acquire DSN S-band (2.3-GHz) data for a day or two in order to improve the VSOP orbit accuracy, enhancing the likelihood of immediate link acquisition. As K_u-band data is acquired from the U.S. tracking stations, analysis of the quality of the phase residuals, Doppler data, and derived orbit must be made. The K_u-band link checks may take several weeks from beginning to end, including all required data analysis. However, once there is good reason to believe that an orbit of sufficient accuracy for fringe detection has been derived, the first 1.6-GHz fringe checks should be made.

3.6 1.6-GHz Fringe Check (FC-1, FC-2, FC-3, FC-4)

The first 1.6-GHz fringe check should take place as soon as there is an orbit of sufficient accuracy to expect to find fringes. The main elements involved will be the near-real-time (NRT) correlator at Usuda, the 10m tracking station at Usuda, and the 64m telescope at Usuda. However, in this case, as in all interferometer tests, at least two GRTs should be used so that the proper operation of the GRTs can be verified. Since rapid data turnaround is required, the 34m telescope at Kashima is the logical choice as the second GRT, to prevent reliance on the much slower shipping of data from a telescope outside Japan. The array used here constitutes J1, in the definition of Section 3.1. Following processing of data at the NRT correlator, the data should be sent to the VSOP correlator at Mitaka for re-correlation and more detailed analysis.

Co-observing with other telescopes outside Japan should also be scheduled within a few days of the first fringe check, in order to prevent large time delays in case there are initial difficulties in finding fringes with only the elements in Japan. The logical set of telescopes to use for rapid fringe-finding is a set of VLBA telescopes, possibly with a larger telescope involved. The basic array here is NRAO-1.

In some cases, it may be desirable to record link data on multiple recorders simultaneously, in order to facilitate fringe-searching using multiple correlators and the same spacecraft data. However, the logistics of this process are rather daunting, so the simultaneous recording may be delayed until 22-GHz fringe checks.

Initial fringe-check observations should last for approximately 1–3 hours per source. If two sources are employed, the observations may last a total of 6 hours. The current schedule indicates that 1.6-GHz fringe checks will begin near the end of February 1997, when the Sun is between 22^h and 23^h right ascension. Figures 1 and 2 show 24-hr (u,v) coverages for mid-February and mid-March, giving some indication of the best directions in the sky to use. It has generally been believed that the initial fringe verification should be done using observations of OH maser sources. Unfortunately, Orion-KL, which is well resolved, may be the only strong OH maser source that will be available. In addition, maser observations would be complicated by the frequency shift of the lines during the observation. Therefore, the use of strong continuum sources may be a better choice than use of line sources. Possible candidate sources in the north have been chosen from the Pearson-Readhead survey (ApJ, 328, 114, 1988), while those near the equator have been selected from the TDRSS experiments. The best candidates include 0016+731, 0804+499, 0814+425, 3C 273, 3C 279 (1253−055), 1504−167, 1510−089, and 1519−273. Unfortunately, some very compact TDRSS sources (NRAO 530, 1741−038, 1921−293, 1958−179, and 2216−038) will be too close to the Sun. The uniform information provided by the 5-GHz pre-launch VLBA survey of candidate sources for the VSOP survey program may be very useful in choosing the best candidate sources at 1.6 GHz.

The initial 1.6-GHz data would be used for several purposes, listed below:

(1) First fringe detection
(2) Test of orbit-determination accuracy
(3) Consistency check and model check of different correlators
(4) Test of two-way phase methods
(5) Analysis of system coherence (perhaps better done at 5 GHz, due to possible dominance by the interplanetary medium)
(6) Analysis of system calibration
(7) End-to-end system tests (tracking stations, data transfer, correlators, etc.)

The time period required for the first fringe acquisition is difficult to predict. Although it was quite a different situation, the only previous experience we have is with the TDRSS experiment, when approximately 3 weeks were required after the first VLBI observation until the first fringes were detected. The TDRSS spacecraft and system were not built for VLBI as VSOP has been, but all the spacecraft and non-VLBI ground systems were quite mature, so only the VLBI aspects of the experiments were in doubt. It is hoped that a period shorter than 3 weeks is possible from the first fringe check observation until the time of the first VSOP fringe detection. If 1.6-GHz fringes are detected quickly, it may be profitable to try a 5-GHz fringe check as soon as possible, provided the AOCS calibration is accurate enough. It also may be desirable to make 1.6-GHz and 5-GHz fringe checks at nearly the same time on occasion, simply by changing the observing frequency on the spacecraft and the GRTs.

3.7 5-GHz Pointing Observations (CAL-2)

Pointing observations at 5 GHz will be started within weeks after the 1.6-GHz pointing observations and fringe checks begin. Continuum observations must be made because of the lack of line sources. Two methods might be used—either single-dish pointing observations of the strongest continuum sources, or interferometry observations of compact sources. Single-dish observations will be handicapped by the fact that Cas-A will be too close to the Sun throughout the period, Cyg-A will be too close to the Sun until early April, and Tau-A will be too close to the Sun after early April. From the current schedule, it appears that Tau-A would be used. For either the single-dish or interferometric pointing observations, antenna gain analyses also will be made.

In the case of single-dish pointing observations, the primary effort will make use of the Usuda 10m tracking station and autocorrelator, as well as S-band telemetry data received at Kagoshima. A secondary effort might be made using tracking stations in the U.S., with the VLBA correlator operated in an autocorrelation mode. In the case of interferometry observations, the main effort also will be made in Japan, using the 64m telescope and 10m tracking station at Usuda, the 34m Kashima telescope, and both the NRT correlator and the VSOP correlator. A secondary effort could be made in the U.S., using either the Goldstone or Green Bank tracking station, at least 2 U.S. telescopes, and the VLBA correlator. (Arecibo might be useful, although it has a limited range of visibility and is not a very experienced VLBI site.) The interferometric pointing checks, if they occur, also could be used as 5-GHz fringe checks.

Since interferometric pointing checks would require the 8m antenna to follow a boresighting pattern while the VSOP spacecraft orbits the Earth, the source structure may lead to a significant change in correlated flux density that could confuse the effects of pointing errors. Several methods can be used to minimize the effect of source structure, and the best choice of observing procedure will combine all of them. It would be best to observe sources and carry out a boresighting pattern while VSOP is near apogee, so that the projected baseline and the source visibility do not change substantially during the execution of the boresighting pattern. Sources known to be very compact, such as some northern sources from the Pearson-Readhead survey, should be employed. Since they are circumpolar, or nearly circumpolar, for northern telescopes, they are easy to observe near apogee. Ideally, observations should be made in a direction that gives a small projected baseline, so that the compact sources remain unresolved throughout the boresighting pattern. Of course, not all the desired conditions can be satisfied while observations are made at a range of different Sun angles, but the best effort should be made to satisfy as many as possible.

Because of the lack of maser and continuum sources, 5-GHz pointing observations will be among the most difficult activities during IOC. It is currently thought that the Sun angle will not have a significant impact on pointing at 5 GHz, which is fortunate because of the paucity of angles that might be sampled. However, some pointing observations still are necessary to confirm this prediction, and 5-GHz gain measurements also are essential.

3.8 First Imaging Observations (IM-1)

The first imaging observation will be a 1.6-GHz continuum observation. This observation will have a variety of purposes, but the primary uses will be to verify the capability of imaging with VSOP and to test all aspects of calibration. There is a tradeoff between using a large number of sensitive telescopes and using a well-understood array of telescopes such as the VLBA, in order to provide the earliest possible results. (The present author favors using well-understood arrays.) In general, two sets of observations should be made. The first set would involve near-equatorial sources, telescopes in Japan and Australia, and correlation in Mitaka (array APT). The second set would involve sources located from the equator to high northern declinations, with telescopes in the U.S. and Europe, and correlation in Socorro (array NRAO-2 or NEVN-LC).

The strawman schedule has the first imaging observations occurring in mid-March 1997. Sample all-sky (u,v) plots for mid-March are shown in Figure 2; for simplicity, those plots were made assuming a full 24-hr track. In fact, the observation will more likely last about 12 hours, with the time window based on source visibility from the GRTs as well as the satisfaction of spacecraft constraints. 3C 279 and 1334−127 may be useful sources that are also of considerable scientific interest. 3C 273 also could be useful, but it is located nearly along the orbit plane, so the coverage will be rather one-dimensional. Candidate sources farther north are the same as those listed in Section 3.6, including 0016+731, 0804+499, and 0814+425.

The first imaging observation would serve purposes similar to the first fringe-finding observation, except that it could enable more extensive comparison of the VLBA and VSOP correlators, and would provide a much better test of coherence, orbit determination, and calibration. It also would play an important role in demonstrating the overall scientific capability of the VSOP mission. Therefore, the observations, data processing and imaging should take place as soon as possible within the IOC period.

The last of the 1.6-GHz imaging observations may be observed with GRTs using dual polarization, in order to check the capability for making polarization images with VSOP. These data would be provided to the Polarization Study Team for them to attempt the full-polarization calibration and imaging. In order to reduce the number of variables in such tests, it is strongly recommended that the ground array be the VLBA in stand-alone mode. The GRTs would have to run at the VLBA-sustainable rate of 128 Megabit/s, which can be accomplished in any of three ways: (1) observe both polarizations in two 16-MHz channels full time, with 1-bit sampling instead of 2-bit sampling; (2) observe both polarizations in only one 16-MHz channel full time, with 2-bit sampling; or (3) observe both polarizations in two 16-MHz channels, with 2-bit sampling, but spin tape for no more than half the elapsed time of the observation. Precise details of the observations should be worked out by the Polarization Study Team.

3.9 5-GHz Fringe Checks (FC-5, FC-6, FC-7, FC-8)

Fringe checks at 5 GHz are required in a similar manner to those made at 1.6 GHz, and the antenna arrays will be nearly the same. Coherence, orbit determination, and correlator performance should be investigated; the coherence measurements may be more meaningful than those at 1.6 GHz, which are likely to be dominated by the interplanetary medium. Since the higher frequency puts more stringent requirements on correlator models and overall system coherence, all tracking stations and correlators should be included in these tests. As mentioned in Section 3.8, some fringe checks may occur in conjunction with interferometric pointing tests.

The best sources to use for fringe checks will be continuum sources that are expected to show high correlated flux densities. DA 193 (0552+398) is a much better candidate source than at 1.6 GHz because of its highly inverted spectrum between 1.6 and 5 GHz; however, it is not available after early April. The other good candidates are basically the same as those at 1.6 GHz (see Section 3.6). The pre-launch strong-source survey made with the VLBA should prove very useful for making the final source selection. Figures 2 and 3 show sample all-sky (u,v) coverages for mid-March and mid-April.

3.10 Initial 22-GHz Pointing Observations (CAL-3)

Without waiting for the 5-GHz continuum results, which may require considerable processing, 22-GHz pointing observations will be made on water-maser sources, using the Usuda 10m antenna and Usuda autocorrelator on the downlink data. (There are no sources of sufficient strength to make pointing observations on continuum sources, either in single-dish or interferometer mode.) At the same time, similar observations may be made using the Goldstone or Green Bank tracking station, with processing at the VLBA correlator in its autocorrelator mode. The 22-GHz pointing observations also will be used to characterize the antenna gain, so simultaneous single-dish observations with a small GRT may be required to monitor the strengths of the maser sources.

The 22-GHz pointing checks will be made as a function of Sun angle in order to build a pointing model, since it is predicted that the Sun angle will have a noticeable effect on the 22-GHz pointing. Orion-KL will be too close to the Sun, but W49, W51, and Sgr-B2 should be accessible, and other maser sources of sufficient strength may also be used in order to better characterize the dependence of pointing on Sun angle. Since the pointing model will change through the first few months of the mission as the antenna surface reaches its final state, the 22-GHz observations cannot be declared complete until several months after the antenna deploys. We anticipate that 22-GHz pointing observations will be required until a minimum of 4 months after launch.

3.11 5-GHz Test Imaging (IM-2)

Following good convergence on a 5-GHz pointing model, 5-GHz test images should be made. This imaging need not wait until the completion of the 22-GHz pointing tests. The procedure for imaging will be very similar to that for the first 1.6-GHz images. Figure 3 shows the all-sky (u,v) coverage at 5 GHz in mid-April, when the first 5-GHz imaging is anticipated. Most of the best sources used for 1.6-GHz images will still be good candidates; precession of the orbital plane also should make 3C 273 a much better candidate than it is at 1.6 GHz. 3C 345 (1652+398) will be emerging from the Sun-avoidance zone, but it is near the orbital plane, so the synthesized aperture would be quite one-dimensional. Telescope arrays will be basically the same as those used for the first 1.6-GHz imaging checks. Coherence, orbit-determination, correlator, and calibration checks will be among the purposes of the imaging, with the higher frequency observations providing a more stringent test of the end-to-end system. As for the 1.6-GHz imaging, the final test observations should include dual polarization data from the VLBA.

3.12 22-GHz Fringe Checks (FC-9, FC-10, FC-11, FC-12)

Following establishment of a rough pointing model, the first 22-GHz VLBI observations should be made for a fringe check. Sgr B2 and W49 may be good choices for maser sources; Orion-KL and W3 will be too close to the Sun. (The use of water maser sources or continuum sources may depend partly on experience gained from attempts to observe OH masers at 1.6 GHz.) These observations should involve the most sensitive GRTs possible, due to the possible uncertainties in the pointing and gain of the space telescope. The highest possible accuracy also is required in the spacecraft trajectory used in the fringe search. One preferred set of ground elements is the Usuda 10m tracking station used together with the Nobeyama and Kashima radio telescopes, and either the Usuda NRT correlator or the VSOP correlator. The other preferred set may be the Goldstone or Green Bank tracking station, with two large telescopes located in the U.S. or Europe and data being sent to the VLBA correlator. The best candidate telescopes are the phased VLA and Effelsberg, probably along with two VLBA antennas.

The 22-GHz fringe checks also will serve as a critical end-to-end test of the entire Space VLBI system, including tests of phase transfer, overall coherence, orbit determination, and correlators. It would not be surprising if there is some difference among correlators at the level of detail required for the 22-GHz observations, particularly in the parameters related to the space radio telescope (e.g., application of the orbit ephemeris or the time correction files). Hence, tests of different correlators using the same data could be quite important. This would require simultaneous recording on two tape drives at tracking stations and at U.S. telescopes, or shipment of U.S. tapes to Mitaka for copying to VSOP cassettes, before the original tapes are sent back to the VLBA correlator. The logistics of such observations are formidable, so multiple-tape recording probably should be attempted for non-critical low frequency observations first.

The choice of continuum sources at 22 GHz is critical because of the expected low sensitivity of the spacecraft. Here, the selection of sources has been made using the VSOP pre-launch survey and the TDRSS results at 15 GHz, with the source availability shown by the plots in Figures 3 and 4. Possible candidates include 1055+018, 3C 273, 3C 279, 1308+326, 1334−127, 1510−089, 1611+343, 1633+382, 1638+398, 3C 345 (1641+399), NRAO 530 (1730−130), 1741−038, and 1921−293. These sources tend to be quite variable. Therefore, it would be best if flux densities at the February 1997 epoch (or later), from monitoring programs such as that at Metsahövi, could be used to pick the best candidate sources.

3.13 Transition Phase

Following the 22-GHz fringe check, there will be a transition phase during which in-orbit checkout and the first observations for approved scientific programs are done concurrently. Required checkout observations always will take priority, and the general scientific observing programs will initially be limited to about two days per week. The scientific observing then will increase by about one day per week each month, to a maximum of 5–6 days per week. During this time, the IOC activities probably will be dominated by spacecraft characterization and further development of pointing models, particularly at 22 GHz. Spacecraft characterization includes study of such items as the AOCS, and thermal properties of various subsystems as a function of Sun angle and position in the orbit. This characterization actually occurs throughout the IOC, and must be traded off against direct checkouts of radio astronomical properties of satellite. Development of the 22-GHz (and possibly 5-GHz) pointing model cannot be considered finished until the thermal settling of the antenna surface is completed and subsequent observations of calibration sources at a range of Sun angles have been made.

The first scientific observations should encompass a variety of science, including some of the more important scientific projects at 1.6 GHz and (possibly) at 5 GHz. Early observations might include imaging of strong continuum sources at 1.6 GHz, a brightness temperature survey at 1.6 or 5 GHz, measurements of spot sizes of OH masers, and measurements of interstellar broadening at 1.6 GHz. The first programs may be predominantly parts of key science programs, since the principal investigators of those programs will have the greatest incentive to produce results and images as quickly as possible.

3.14 22-GHz Test Imaging

Following reasonable convergence of the 22-GHz pointing, the first 22-GHz images will be made. This will serve as the final scheduled check of phase transfer, coherence, orbit determination, correlators, and calibration. (Polarization also may be checked by making dual-polarization ground observations with the VLBA for one of the last test images.) The image quality will depend critically on the fine details of these items. Since it will be rather difficult to predict which sources will be resolved out and which will show strong fringes, several should be observed. These observations are currently scheduled for mid-May 1997; all-sky (u,v) coverages for that time, and for a time one month later, are shown in Figures 4 and 5. Good candidate sources include those specified for fringe checks in Section 3.12. However, most of the listed sources having right ascensions of 12^h and higher are poor candidates for imaging, because their (u,v) coverage is quite one-dimensional.

3.15 Routine Scientific Observations

At some point, the IOC will be declared complete by the VSOG, and routine scientific observations will begin. During this time, regular spacecraft checks will be made on a weekly basis. Updates of the pointing tables will be made as necessary. As discussed in Section 3.14, the current plan is that the transition period will start with about 2 days per week of scientific observing. We anticipate that this will increase by about 1 day per week each month until reaching a final value of 5–6 days per week.

3.16 Summary of Candidate Sources

A summary of some possible continuum candidates for early imaging and fringe checks in all three VSOP frequency bands is given in Table 1. As noted previously, results from the VLBA pre-launch survey at 5 GHz (particularly the long baseline between Mauna Kea and Saint Croix) and from flux-density monitoring at 22 GHz should provide more up-to-date information that will enable the choice of the best candidate sources.

Table 1. Some candidate sources for fringe-checks and imaging

Freq.	Month	Ground Array	Sources
1.6 GHz	2/97–3/97	Asia + South	3C 273, 3C 279, 1504−167, 1510−089, 1519−273
1.6 GHz	2/97–3/97	VLBA	0016+731, 0804+499, 0814+425, 3C 273, 3C 279
1.6 GHz	2/97–3/97	EVN	0016+731, 0804+499, 0814+425, 3C 273, 3C 279
5 GHz	3/97–4/97	Asia + South	3C 273, 3C 279, 1504−167, 1510−089, 1519−273
5 GHz	3/97–4/97	VLBA	0016+731, DA 193, 0804+499, 0814+425, 3C 273, 3C 279
5 GHz	3/97–4/97	EVN	0016+731, DA 193, 0804+499, 0814+425, 3C 273, 3C 279
22 GHz	4/97–5/97	Asia + South	3C 273, 3C 279, 1334−127, 1749+096, 1921−293
22 GHz	4/97–5/97	VLBA	3C 273, 3C 279, 1334−127, 1611+343, 1749+096
22 GHz	4/97–5/97	EVN	3C 273, 3C 279, 1334−127, 1611+343, 1749+096

4. PHILOSOPHY OF GROUND RADIO TELESCOPE USAGE

This section summarizes the philosophy for use of GRTs during IOC, for fringe checks and imaging checks. The basic layout of the detailed IOC plan is that VLBI observations using Japanese and other telescopes would occur for 3 hours almost every Tuesday (UTC), for the purposes of fringe checks. VLBI observations using various arrays of telescopes would occur almost every Thursday, for either fringe-check or imaging tests.[1] The length of time given for each observation is assumed to be approximately the length of time for each individual array of GRTs to observe a source. Imaging checks are assumed to last 12 hours (2 VSOP orbits) per observation, while fringe checks with arrays of 4–5 telescopes are assumed to take 6 hours, amounting to one complete VSOP orbit.

Most observations could slide one or more weeks earlier or later, depending on the progress of the in-orbit checkout. In addition, fringe-check or imaging observations scheduled on successive weeks often have the same basic parameters, so that it would be possible to change schedules merely by changing an observing frequency or (perhaps) a source name. This would reduce the likelihood that a large amount of re-scheduling would need to be done on a short time scale. (If IOC proceeds more rapidly than indicated in the schedule, some observations could even be cancelled!) It is easily possible to combine fringe checks at two frequencies (especially 1.6 and 5 GHz) on the same day, either by changing frequencies on the spacecraft or by making simultaneous dual-frequency observations (less promising because of the lower signal-to-noise achieved by having only one 16-MHz channel in each frequency band). The present plan includes only a single frequency band for a given day of fringe checks. However, the selection of frequencies given in the plan below is an educated guess which should be re-assessed frequently during the course of the IOC.

Many GRTs are included in this version of the IOC plan. It is assumed that those telescopes will have been "certified" to be reliable telescopes by some means prior to VSOP launch, so that they can be used to effectively test the space radio telescope, and so that problems with the GRTs or GRT/correlator interfaces do not take up extra time during IOC. Telescopes which are not known to be reliable before the beginning of IOC may be used considerably less than the amount illustrated in the current plan, or may not be used at all.

[1] The selection of Tuesday and Thursday for GRT participation implies that all observatories can take part in these tests on a local weekday rather than on the weekend.

5. IOC TIMELINE

This section contains a possible general timeline for the different elements of the IOC, including those described in Sections 3 and 4. The timeline is based on the assumption of a launch date of January 20, 1997, and telescope deployment on January 31, 1997. The timeline can be met only by a focused effort from a well-integrated (and well-populated!) IOC team.

EVENT	RANGE OF DATES
Launch	20 JAN
Antenna Deployment	31 JAN
SC Checks	01 FEB–01 MAR
AOCS Check	01 FEB–15 MAR
OPS Checks	01 FEB–15 MAR
NAV & GPS Checks	01 FEB–30 MAR
K_u Link Checks	15 FEB–25 MAR
Receiver Checks	13 FEB–24 FEB
1.6-GHz Antenna Check	13 FEB–14 FEB
1.6-GHz Pointing Check	18 FEB–22 FEB
1.6-GHz Fringe Checks	25 FEB–13 MAR
1.6-GHz Imaging Checks	20 MAR–3 APR
5-GHz Pointing Checks	5 MAR–17 MAR
5-GHz Fringe Checks	18 MAR–8 APR
22-GHz Pointing Checks	26 MAR–16 MAY
5-GHz Imaging Checks	10 APR–1 MAY
22-GHz Fringe Checks	15 APR–13 MAY
22-GHz Image Checks	8 MAY–29 MAY
Transition Phase Start	12 MAY
General Observing: 2 days/week	12 MAY–14 JUN
General Observing: 3 days/week	16 JUN–12 JUL
General Observing: 4 days/week	14 JUL–16 AUG
General Observing: 5 days/week	18 AUG–13 SEP
End Transition; Observing $\geq$5 days/week	15 SEP

6. A POSSIBLE DAY-TO-DAY PLAN

This section gives a possible day-to-day plan for about four months of IOC. The plan indicates the major types of activity to be carried out on each day, according to the definitions given in Section 3. Off-line analysis of data and refinement of initial results are generally not shown. For VLBI observations, the required mission elements used for particular observations are given, generally using the array definitions established in Section 4.1. This plan is moderately success-oriented; it generally assumes that activities such as imaging checks are fairly successful on the second round of attempts. After the first few weeks of the plan, each week is assumed to include six days of general activities, with the 7th day (Sunday) used only for routine phase links and acquisition of Doppler data. Figures 6–9 give rough timelines for the months from February through May 1997.

<u>Week 1</u>
1/20 Launch
1/21 Trajectory Correction Maneuver (TCM) 1
1/22 Attitude Control System (ACS) check
1/23 ACS, bus instruments check
1/24 TCM 2
1/25 Bus instruments check
1/26 TCM 3

<u>Week 2</u>
1/27 Bus instruments check
1/28 TCM 4
1/29 Bus instruments check
1/30 Pre-heat antenna; subreflector deployment
1/31 Main reflector deployment; K_u antenna deployment
2/1 SC-1, SC-2, AOCS-1, AOCS-2, NAV-1, TRK-1
2/2 SC-1, SC-2, AOCS-1, AOCS-2, NAV-1, TRK-1

<u>Week 3</u>
2/3 SC-1, SC-2, AOCS-1, AOCS-2, AOCS-3, NAV-1, TRK-1
2/4 SC-1, SC-2, AOCS-1, AOCS-2, AOCS-3, NAV-1, TRK-1, OPS-1
2/5 SC-2, AOCS-1, AOCS-2, AOCS-3, NAV-1, TRK-1
2/6 SC-2, AOCS-3, NAV-1, TRK-1
2/7 SC-2, AOCS-3, AOCS-4, NAV-1, TRK-1
2/8 SC-2, AOCS-3, AOCS-4, NAV-1, TRK-1
2/9 SC-2, AOCS-3, AOCS-4, NAV-1, TRK-1

<u>Week 4</u>
2/10 SC-2, AOCS-4, AOCS-5, NAV-1, TRK-1
2/11 SC-2, AOCS-5, NAV-1, TRK-1, OPS-2
2/12 SC-2, AOCS-5, NAV-1, NAV-2, TRK-1
2/13 SC-2, SC-3, SC-4, SC-7, AOCS-5, NAV-1, GPS-1, TRK-1
2/14 SC-2, SC-3, SC-4, SC-5, SC-6, SC-7, AOCS-5, NAV-1, GPS-2, TRK-2
2/15 SC-2, SC-3, SC-4, SC-5, SC-6, AOCS-5, NAV-1, NAV-4, GPS-3, TRK-2, TRK-3
2/16 SC-2, AOCS-5, NAV-1, NAV-4, GPS-3, TRK-3

Week 5
2/17 SC-2, SC-3, AOCS-5, NAV-1, NAV-4, GPS-4, TRK-3
2/18 SC-2, SC-8, AOCS-5, NAV-1, NAV-3, NAV-4, GPS-5, TRK-3, OPS-2, CAL-1
2/19 SC-3, SC-8, AOCS-6, NAV-4, GPS-6, TRK-3, CAL-1
2/20 SC-8, AOCS-6, NAV-4, GPS-6, TRK-4, OPS-3, CAL-1
2/21 SC-9 AOCS-6, NAV-4, GPS-7, TRK-2, TRK-4, OPS-3, CAL-1
2/22 SC-9, AOCS-6, NAV-5, TRK-2, TRK-5, OPS-4, OPS-5, CAL-1, CAL-4
2/23 AOCS-6, NAV-5, TRK-5, OPS-3

Week 6
2/24 SC-4, SC-9, AOCS-6, NAV-5, GPS-7, TRK-5, OPS-4, OPS-5, CAL-4
2/25 AOCS-6, NAV-6, TRK-6, OPS-2, OPS-4, OPS-5, OPS-6, FC-1 (J1), COR-1, CAL-4, CAL-5, CAL-6
2/26 AOCS-6, NAV-6, TRK-5, OPS-4, OPS-5
2/27 AOCS-6, NAV-6, TRK-6, TRK-9, OPS-4, OPS-5, OPS-6, FC-1 (J1), FC-3 (NRAO-1, EVN-LC), COR-4, COR-5, CAL-4, CAL-5, CAL-6
2/28 SC-5, AOCS-6, NAV-6, TRK-5, OPS-4, OPS-5
3/1 SC-5, AOCS-6, NAV-6, TRK-5, OPS-4, OPS-5
3/2 Rest/makeup day

Week 7
3/3 AOCS-7, NAV-6, GPS-7, TRK-5, OPS-4, OPS-5, CAL-1
3/4 AOCS-7, NAV-6, TRK-6, OPS-2, OPS-4, OPS-5, OPS-6, FC-1 (J1), FC-4 (AJ1), COR-1, COR-6, CAL-4, CAL-5, CAL-6
3/5 AOCS-7, NAV-6, TRK-5, OPS-4, OPS-5, CAL-2
3/6 AOCS-7, NAV-6, TRK-6, OPS-4, OPS-5, OPS-6, FC-2 (J1), FC-3 (NRAO-1), COR-2, COR-5, CAL-4, CAL-5, CAL-6
3/7 AOCS-7, NAV-6, TRK-5, OPS-4, OPS-5, CAL-2
3/8 AOCS-7, NAV-6, TRK-5, CAL-2
3/9 Rest/makeup day

Week 8
3/10 AOCS-7, NAV-7, GPS-7, TRK-5, CAL-2
3/11 AOCS-7, NAV-7, TRK-6, TRK-8, OPS-4, OPS-5, OPS-6, FC-1 (J1), FC-4 (AJ1), COR-1, COR-6, CAL-4, CAL-5, CAL-6
3/12 AOCS-7, NAV-7, TRK-5, OPS-4, OPS-5, CAL-2
3/13 AOCS-7, NAV-7, TRK-6, TRK-7, OPS-4, OPS-5, OPS-6, FC-2 (AJ1, US-S2), FC-3 (NRAO-1, EVN-LC), COR-3, COR-5, CAL-4, CAL-5, CAL-6
3/14 AOCS-7, NAV-7, TRK-5, OPS-4, OPS-5, CAL-2
3/15 AOCS-7, NAV-7, TRK-5, OPS-4, OPS-5, CAL-2
3/16 Rest/makeup day

Week 9

3/17 NAV-7, GPS-7, CAL-2
3/18 NAV-7, TRK-6, FC-5 (J1), COR-1
3/19 NAV-7
3/20 NAV-7, TRK-6, TRK-7, IM-1 (APT, NEVN-LC), COR-3, COR-5
3/21 SC-6, NAV-7
3/22 SC-6, NAV-7
3/23 Rest/makeup day

Week 10

3/24 NAV-7, GPS-7, CAL-3
3/25 NAV-7, TRK-6, FC-5 (J1), FC-6 (US-S2), FC-7 (NRAO-1, EVN-LC), COR-4, COR-5
3/26 NAV-7, CAL-3
3/27 NAV-7, TRK-7, IM-1 (NEVN-LC), COR-5
3/28 NAV-7, CAL-3
3/29 NAV-7, CAL-3
3/30 Rest/makeup day

Week 11

3/31 GPS-7, CAL-3
4/1 FC-5 (J1), FC-7 (NRAO-1), FC-8 (AJ1), COR-1, COR-5, COR-6
4/2 CAL-3
4/3 TRK-8, TRK-10, CAL-7, FC-4 (AJ1, US-S2), IM-1 (VLBA), COR-5, COR-6
4/4 CAL-3
4/5 CAL-3
4/6 Rest/makeup

Week 12

4/7 CAL-2, CAL-3
4/8 FC-5 (J1), COR-1
4/9 CAL-2, CAL-3
4/10 TRK-7, TRK-10, IM-2 (APT, NRAO-2), COR-3, COR-5
4/11 CAL-3
4/12 CAL-3
4/13 Rest/makeup

Week 13

4/14 CAL-2, CAL-3
4/15 FC-6 (US-S2), FC-9 (J2), COR-1, COR-6
4/16 CAL-2, CAL-3
4/17 IM-2 (NEVN-LC), COR-5
4/18 CAL-3
4/19 CAL-3
4/20 Rest/makeup

Week 14

4/21 CAL-3
4/22 FC-9 (J2), COR-1
4/23 CAL-3
4/24 FC-10 (J2), FC-11 (NRAO-1, EVN-K), COR-2, COR-5
4/25 CAL-3
4/26 CAL-3
4/27 Rest/makeup

Week 15

4/28 CAL-3
4/29 FC-9 (J2), FC-11 (NRAO-1, EVN-K), COR-1, COR-5
4/30 CAL-3
5/1 CAL-7, IM-2 (APT, VLBA), COR-5, COR-6
5/2 CAL-3
5/3 CAL-3
5/4 Rest/makeup

Week 16

5/5 CAL-3
5/6 FC-9 (J2), FC-11 (NRAO-1), COR-1, COR-5
5/7 CAL-3
5/8 IM-3 (NEVN-K), COR-5
5/9 CAL-3
5/10 CAL-3
5/11 Rest/makeup

Week 17

5/12 SCI-1
5/13 FC-9 (J2), FC-12 (AJ2), COR-2, COR-3
5/14 CAL-3
5/15 IM-3 (AJ2, NRAO-2), COR-3, COR-5
5/16 CAL-3
5/17 SCI-1
5/18 Rest/makeup

Week 18

5/19 SCI-1
5/20 FC-9 (J2), FC-12 (AJ2), COR-1, COR-6
5/21 CAL-3
5/22 IM-3 (NEVN-K), COR-5
5/23 CAL-3
5/24 SCI-1
5/25 Rest/makeup

Week 19

5/26 SCI-1
5/27 FC-9 (J2), FC-12 (AJ2), COR-2, COR-6
5/28 CAL-3
5/29 CAL-7, IM-3 (AJ2, VLBA), COR-5, COR-6
5/30 CAL-3
5/31 SCI-2
6/1 Rest/makeup

7. GROUND RADIO TELESCOPE USAGE

7.1 Summary of VLBI Observations During IOC

The philosophy of the IOC plan, as stated previously, is to enable observations to slip by integer multiples of one week without requesting any additional telescope time. On the following page, we show the GRT observations that have been included for fringe checks and imaging checks. Correlator usage also is included. Here, remember that COR-1 is the Usuda NRT correlator; COR-2, COR-3, and COR-4 all represent the Mitaka correlator with different types of input tapes from tracking stations; COR-5 is the VLBA correlator; and COR-6 is the Penticton correlator. FC-1 through FC-4, and IM-1, are 1.6-GHz observations. FC-5 through FC-8, and IM-2, are 5-GHz observations. FC-9 through FC-12, and IM-3, are 22-GHz observations.

Section 4 states that the IOC should use primarily "certified" telescope and correlator systems. These combinations are those that are known to provide good results on ground baselines without "heroic" efforts at the correlator facilities. If possible, the correlators also should satisfy some set of tests showing that they can properly process data from the space radio telescope (VLBI data, reconstructed orbits, and time correction files from combinations of the VSOP spacecraft and various tracking stations). The detailed plan for VLBI observations laid out below calls upon a wide range of telescope and correlator resources, and the VSOP mission cannot afford to spend its time on these resources if they have not been checked thoroughly before launch. Therefore, those resources that have not been "certified" may be dropped from the plan below, particularly during the early stages of IOC when rapid turnaround of results is necessary for the IOC process to progress.

Day-by-Day VLBI Observations

February 1997
2/25 FC-1 (J1), COR-1
2/27 FC-1 (J1), FC-3 (NRAO-1, EVN-LC), COR-4, COR-5

March 1997
3/4 FC-1 (J1), FC-4 (AJ1), COR-1, COR-6
3/6 FC-2 (J1), FC-3 (NRAO-1), COR-2, COR-5
3/11 FC-1 (J1), FC-4 (AJ1), COR-1, COR-6
3/13 FC-2 (AJ1, US-S2), FC-3 (NRAO-1, EVN-LC), COR-3, COR-5
3/18 FC-5 (J1), COR-1
3/20 IM-1 (APT, NEVN-LC), COR-3, COR-5
3/25 FC-5 (J1), FC-6 (US-S2), FC-7 (NRAO-1, EVN-LC), COR-4, COR-5
3/27 IM-1 (NEVN-LC), COR-5

April 1997
4/1 FC-5 (J1), FC-7 (NRAO-1), FC-8 (AJ1), COR-1, COR-5, COR-6
4/3 FC-4 (AJ1, US-S2), IM-1 (VLBA), COR-5, COR-6
4/8 FC-5 (J1), COR-1
4/10 IM-2 (APT, NRAO-2), COR-3, COR-5
4/15 FC-6 (US-S2), FC-9 (J2), COR-1, COR-3
4/17 IM-2 (NEVN-LC), COR-5
4/22 FC-9 (J2), COR-1
4/24 FC-10 (J2), FC-11 (NRAO-1, EVN-K), COR-2, COR-5
4/29 FC-9 (J2), FC-11 (NRAO-1, EVN-K), COR-1, COR-5

May 1997
5/1 IM-2 (APT, VLBA), COR-5, COR-6
5/6 FC-9 (J2), FC-11 (NRAO-1), COR-1, COR-5
5/8 IM-3 (NEVN-K), COR-5
5/12 SCI-1
5/13 FC-9 (J2), FC-12 (AJ2), COR-2, COR-3
5/15 IM-3 (AJ2, NRAO-2), COR-3, COR-5
5/17 SCI-1
5/19 SCI-1
5/20 FC-9 (J2), FC-12 (AJ2), COR-1, COR-6
5/22 IM-3 (EVN-K), COR-5
5/24 SCI-1
5/26 SCI-1
5/27 FC-9 (J2), FC-12 (AJ2), COR-2, COR-6
5/29 IM-3 (AJ2, VLBA), COR-5, COR-6
5/31 SCI-2

7.2 Total Time Requested, by Array

Table 2 summarizes the total time requested for in-orbit checkout observations for each of the arrays. This time would be requested during the period between February 1997 and May 1997. More checkout observations may be needed later than May 1997, but these needs have not yet been analyzed. In this section, the totals for the NRAO and EVN arrays that are included as part of the NEVN have been listed separately. It is assumed that the short fringe check observations on Tuesdays require 3 hours, the longer fringe check observations on Thursdays require 6 hours, and imaging observations require 12 hours.

Table 2. Sessions Required from Arrays

Array	3-hr FC	6-hr FC	12-hr IM
J1	7	2	0
J2	7	1	0
AJ1	3	2	0
AJ2	3	0	2
APT	0	0	3
EVN-LC	1	2	3
EVN-K	1	1	2
NRAO-1	4	4	0
NRAO-2	0	0	6
VLBA	0	0	3
US-S2	4	0	0

7.3 Total Time Requested, by Telescope

Table 3 summarizes the total time requested for each individual GRT, as taken from the arrays summarized above. A direct request for GRT time during the period from February 15 through July 15, 1997, which may differ somewhat from the present plan, will be made by September 15, 1996.

Table 3. Sessions Required from Individual Telescopes

Telescope	3-hr FC	6-hr FC	12-hr IM
Usuda	10	4	3
Kashima	20	5	5
Nobeyama	10	1	2
Parkes or ATCA	6	2	5
Hobart and/or Mopra	6	2	5
Tidbinbilla	5	2	4
Hart	0	0	3
Effelsberg	2	3	5
Jodrell	1	2	3
Noto	2	3	5
Onsala	2	3	5
Medicina	1	2	3
Westerbork	1	2	3
Madrid	1	3	3
Goldstone	1	3	3
Green Bank	10	7	7
3–4 VLBA	4	4	0
10 VLBA	0	0	3
Arecibo	4	0	0

Figure Captions

(1) All-sky (u,v) coverages at 1.6 GHz on February 15, 1997, with different ground arrays. Points are plotted only when four antennas can see a source, and only every 10th ground-ground baseline is plotted. All observations are assumed to last from 0^h until 24^h UT. (a) VLBA. (b) EVN. (c) Array of Asian and southern antennas.

(2) All-sky (u,v) coverages at 1.6 GHz on March 15, 1997, with different ground arrays. Plot parameters are as described for Figure 1. (a) VLBA. (b) EVN. (c) Array of Asian and southern antennas.

(3) All-sky (u,v) coverages at 5 GHz on April 15, 1997, with different ground arrays. Plot parameters are as described for Figure 1. (a) VLBA. (b) EVN. (c) Array of Asian and southern antennas.

(4) All-sky (u,v) coverages at 22 GHz on May 15, 1997, with different ground arrays. Plot parameters are as described for Figure 1. (a) VLBA. (b) EVN. (c) Array of Asian and southern antennas.

(5) All-sky (u,v) coverages at 22 GHz on June 15, 1997, with different ground arrays. Plot parameters are as described for Figure 1. (a) VLBA. (b) EVN. (c) Array of Asian and southern antennas.

(6) IOC timeline for February 1997, numbering activities according to the definitions provided in Section 2.

(7) IOC timeline for March 1997.

(8) IOC timeline for April 1997.

(9) IOC timeline for May 1997.