

**NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia**

June 6, 1994

MEMORANDUM

To: GBT Memo Series Distribution
From: Robert D. Hall
Subject: GBT Phases

The purpose of this memorandum is to define the phases of the Green Bank Telescope project starting with construction and proceeding on through to high frequency operation. A clear definition of the phases and an understanding of the construction and installation operations will lead to the efficient and timely integration of NRAO furnished functional equipment and enhancements while shortening the time span to achievement of successful operation at higher frequencies. The various phases are delineated as follows:

PHASE 0 - CONTRACTOR'S PHASE

Phase 0 involves all activities leading up to the delivery of a fully operational antenna. This phase will be considered completed upon issuance of a provisional acceptance by NRAO that the antenna and control system fully comply with GBT specifications.

In accordance with the contract, the Contractor is required to demonstrate antenna compliance with any or all operational and performance specifications. This proof of performance is accomplished progressively and includes testing of components and subsystems in the Contractor's and Subcontractors' plants and at the site; field alignments of the axes, encoders and reflector surface; operational and performance tests; and by calculations.

- Acceptance tests for the drive and feed arm servo systems are delineated in sections 03.7.2.8 and 03.7.3.5 of the Contractual Specification, AUI-1059, Rev. B, dated August 10, 1993.
- Tests and field alignments to be conducted on the components and subsystems of the antenna to demonstrate conformance of the required characteristics or proper operation are specified in section 03.11.4.2 of the specification.

- Reflector surface accuracy tests are specified in section 03.11.4.3.
- The Contractor shall submit test procedures and data sheets to NRAO for approval before tests are conducted.
- Approval of a test plan does not preclude NRAO from requiring additional testing.

Contractor's Responsibilities with Respect to NRAO-Furnished Equipment (Phase 0)

Extracts from Contractual Specification:

AUI Requirements	Contractor Requirements
03.9. (5) Active Surface:	
a) AUI designs and provides actuators, motors and transducers. AUI provides control electronics.	a) Contractor installs and wires (to control actuator room in elevation structure) motors, actuators, and transducers. Establishes zero on actuators.
b) AUI designs and furnishes retroreflector assembly to be mounted over actuator.	b) Contractor installs retroreflector assembly. Adjusts surface to 0.040" rms.
c) AUI shall improve the surface measuring/setting from .040" to 0.018" rms.	
A. The Contractor will install the 2213 active surface actuators in a zero position, i.e., midway in the total actuator travel, and install and identify the actuator control cables from the actuator locations back to the actuator control room.	
● The Contractor will remove the actuators from the NRAO shipping containers and install the surface panel support brackets ("hat sections") at the top of each actuator.	
● The Contractor presently plans to install the actuators and the actuator cables as the backup structure is constructed on the ground. Cables will be coiled and stowed to protect them while the 22 modules are raised to position and installed on the box structure. After erection of the backup structure, actuator cables will be routed through the backup structure to the actuator control room. NRAO may choose to participate in a check of the cables at this point to ascertain if any damage has occurred during erection.	
● The Contractor has elected to install the surface panels prior to final adjustment of actuator heights. Surface panels will be installed with the reflector at an elevation angle of 66°. Setting measurements will be corrected to allow for the gravity deflection between 44° (the rigging angle) and 66°.	

- Using an Electronic Distance Measuring (EDM)-theodolite located at the vertex, the Contractor will bring the tops of all actuators, and thus the retroreflectors which will be installed later, to a true position within $\pm \frac{1}{8}"$ (this represents the 3σ point of the 0.040" rms specified in the contract). Setting accuracy will be achieved by using the four adjusting screws at the base of the actuator support bracket. Final measurements and adjustments will be made after the surface panels are in place. The adjustable actuator support brackets will be locked in place by welding after verification of the setting tolerance by the Contractor and NRAO.
- Using the NRAO supplied corner setting tool, the Contractor will adjust the corners of all panels to compensate for the use of only sixteen manufacturing molds to build the forty-four different configurations of surface panels.

Discussion

NRAO has specified a measuring and setting tolerance of 0.040" rms (see surface accuracy table below) thus allowing the Contractor to set the surface using standard theodolite-distance measurement techniques with resultant savings in both time and money. When the actuators become operational (Phase II) these peak errors ($\pm \frac{1}{8}"$) will be eliminated by resetting the actuators to the correct heights electronically. No further manual adjustments of the surface by NRAO personnel will be required. The accurate measurements needed for this operation will be done by holography. The reflector will be rotated to an elevation angle of 45° for holographic measurements to take advantage of a 12 GHz geostationary telecommunications satellite.

Performance (Phase 0)

The Contractor must demonstrate conformance to the performance requirements of the specification by calculation and/or by testing.

	as delivered by RSI mm(in.)
Surface Panel:	
Manufacturing	0.075 (0.003)
Gravity	0.100 (0.004)
Temperature	0.100 (0.004)
Wind	0.050 (0.002)
CMM Measurement System	0.025 (0.001)
Antenna Structure:	
Gravity	1.040 (0.041)
Temperature	0.130 (0.005)
Wind	0.280 (0.011)
Measuring and Setting	0.450 (0.018)*
Subreflector	0.050 (0.004)
Total Surface Accuracy:	
Maximum temperature	1.15 (0.045)
Maximum wind	1.18 (0.046)
Specified Surface Accuracy	1.25 (0.049)

- * Reference section 03.9 (5) which allows the Contractor to adjust the surface to 0.040" rms. NRAO will improve the surface measuring/setting from 0.040" to 0.018" rms. As noted above, NRAO has elected to initially bypass the 0.450 (0.018") requirement and improve the surface measuring and setting tolerance when the actuators become operational in Phase II.

Pointing Accuracy

Pointing Accuracy	Non-Repeatable without wind and thermals	Total Non-Repeatable including wind and thermals
	7 arc seconds	14 arc seconds

03.9.(8) Active Surface Control Room

AUI specifies equipment room for active surface electronics and provides electronic racks (25).

Contractor designs, provides, and installs equipment room. Installs electronic racks.

- NRAO will not provide 25 electronic racks for the Contractor to install in the actuator control room. Under the present plan TTI equipment will be used instead of the originally planned NRAO built electronic racks. The actuator control system consists of control panels supported by aluminum frames which will be installed by NRAO.
- The actuator control room will be available at the site early in the erection cycle and installation of the control equipment may begin while the room is located on the ground. Following installation of Contractor furnished equipment, NRAO will install cable entry plates, grommets, cable trays, equipment mounting frames, etc. The Contractor will provide temporary power, HVAC, etc., to the room as required. Any additions to the building such as drip protection for the cables as they enter, must be added at this time.
- At the appropriate point during erection, the actuator control room will be raised and installed by the Contractor. When the actuator cables have been routed through the structure to the control room, the Contractor will install each cable in the proper entry port and in its individual grommet. All actuator cables will be identified and checked by the Contractor after final installation employing a mutually agreed upon test plan. It is anticipated that the Contractor will install test plugs sequentially at each actuator to facilitate testing.

03.9 (6a) Feed Support Arm

a) (Deleted)

b) AUI specifies the subreflector.

c) AUI specifies subreflector adjustment device.

a) (Deleted)

b) Contractor designs, provides, and installs the subreflector.

c) Contractor design, provides, and installs subreflector adjustment device.

- The Contractor will deliver the subreflector directly to the site from Sterling, Virginia late in 1994. The upper end of the feed arm, the subreflector adjustment device and the feed arm servo will be assembled and tested in Mexia, Texas during the same time frame. Following the testing, the upper end of the feed arm and the adjustment device will be shipped to Green Bank early in 1995.
- The Contractor will construct a foundation, reassemble the upper end of the feed arm, install the adjustment device, and mount the subreflector at the Green Bank site. The subreflector surface will be set to a .010" rms by the Contractor using dual electronic theodolites. It is NRAO's responsibility to improve the surface rms to 0.004". Present plans involve the use of photogrammetry. The Contractor is responsible for making adjustments to the panels in accordance with NRAO provided photogrammetric data.
- To date, NRAO has not been informed by the Contractor regarding the method of measuring and adjusting the subreflector when installed on the structure. Since correction to the position of the subreflector will be a part of the precision pointing system, NRAO must be involved in the achievement of proper accuracies.

03.9. (6f) Electronics

AUI specifies receiver room and provides electronic racks.

Contractor designs, provides, and wires receiver room, including HVAC and lighting. Installs electronic racks.

Electronics

- The receiver room will be available at the site during Phase 0 and preliminary installation of equipment by NRAO can start. The Contractor will provide power, HVAC, etc., as required. Extensive system tests by NRAO will be conducted to minimize start-up problems.
- Installation of cabling for LO, IF, cryogenics, etc., by NRAO must begin on the structure during this phase.

Other Phase 0 Overlapping Activities/Contractor and NRAO

Local Control Center

Construction of the local control center will be started during Phase 0 and will progress to the point where test operations on electronics can be conducted from the control room during Phase I. Provisions must be made for the installation of three six inch conduits to carry cabling from the pintle bearing room to the control room.

Monitor and Control

Initial installation of Monitor and Control racks and cabling by NRAO will be made during Phase 0. The present plan calls for the use of holography to check Contractor surface adjustments. Monitor and control should be ready to drive and point the GBT to accomplish these measurements.

Closed Loop System

During Phase 0, the following operations will be conducted:

- Retroreflectors will be installed by the Contractor (NRAO option).
- Platforms, enclosures, and access for five laser rangars will be designed, procured/built, and installed by NRAO.
- Platforms, enclosures, and access for the quadrant detector system will be designed, procured/built, and installed by NRAO.
- Accommodations for the autocollimator system will be designed, procured/built, and installed by NRAO.

All of the items listed above require the Contractor's agreement and installation must be integrated with the Contractor's schedule.

PHASE I - LOW FREQUENCY OPERATION (15 GHz)

During Phase I, the operational antenna, delivered by the Contractor at the end of Phase 0, is transformed into a functional radio telescope involving the following NRAO activities:

- The local control center will become fully operational.

- The monitor and control system will be integrated with the antenna control system so that the telescope may be pointed to acquire astronomical data. Interfaces with all NRAO systems will be readied.
- Primary and secondary feeds, receivers, backends, LO, IF, and cryogenics will be installed on the structure or in the local control room, along with associated interconnecting cabling.
- Figure of Merit (G/T) will be measured at various frequencies using standard radio sources.
- Pointing and tracking accuracy will be evaluated.
- Programs will be put in place to acquire and process data from the telescope.
- Work on the active surface system will continue. It is planned that the system will be operational by the end of Phase I.
- Ground monuments for the precision pointing system will be installed. The original design for these monuments will be prototyped on the 140 Foot Telescope during Phase 0.

PHASE II - PRECISION OPERATION (43 GHz)

Phase II will be complete when the active surface system is operational and can compensate for gravity deflections of the reflector surface as commanded by a computer program based on data provided by the Contractor and verified by NRAO. To improve pointing accuracy, NRAO is developing an autocollimator and quadrant detector system, which will be used to enhance the pointing capability of the GBT.

- During Phase II, the holography system will be used to provide measurements for the resetting of the 2213 actuators by (electronically) driving them to the positions giving the best fit surface, presumably within $\frac{1}{8}$ " of midstroke. Surface measuring and setting accuracy will thereby be improved from the Contractor's capability of 0.040" rms to ≈ 0.004 " rms.
- Holography measurements will also be used at this point to verify the calculated data provided by the Contractor to operate the actuators and correct for gravity deflections.
- The autocollimator system will be in place to provide pointing accuracy improvements commensurate with the optimized surface accuracy.
- Retrospheres for the precision pointing system will be installed during Phase II.

Surface Accuracy (Phase II)

	mm(in.)
Surface Panel:	
Manufacturing	0.075(0.003)
Gravity	0.100(0.004)
Temperature	0.030(0.0012)
Wind	--
Measurement system	0.025(0.001)
Antenna Structure:	
Gravity	0.200(0.008)
Temperature	0.300(0.012)
Wind	--
Measuring and Setting	0.100(0.004)
Subreflector	0.100(0.004)
Total Surface Accuracy:	0.409(0.016)
Maximum temperature	n/a
Maximum wind	n/a
Specified Surface Accuracy	0.436(0.017)

Pointing Accuracy (Phase II)

Pointing Accuracy	Non-Repeatable without wind and thermals ≈ 3 arc seconds
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PHASE III - HIGH FREQUENCY OPERATION

This phase will involve bringing the telescope into operation at millimeter wavelengths. This will be accomplished using the laser ranger measurement system and actuators in a closed loop surface adjustment system to compensate for both gravitational and thermal structural deflections. The laser ranger precision pointing system will allow the telescope to be pointed to approximately 1 arc second.