MAJOR CONSTRUCTION: THE GREEN BANK TELESCOPE

GBT Program Plan 1996

Antenna Construction

Since the submission of the 1995 Program Plan, significant progress has occurred in the growth of the Green Bank Telescope antenna structure. As may be seen by a comparison of the photograph included in last year's Program Plan with the photo included here, much headway has been made surrounding the elevation bearing and shaft installation.

During April 1995, all welding was completed on the elevation shaft on the ground. The bearing housings were set in place atop the alidade towers, some 165 feet above ground level. The housings were accurately leveled and positioned to receive the two segments of the 150 foot long shaft. Axle support cradles were placed midway between the alidade towers on the temporary support tower which had been erected earlier. The el shaft was raised in two lifts during the first week of May. Each segment weighed slightly over 100 tons. When the shaft was placed, the two sections were pulled together and precisely aligned using a complex jacking arrangement, thus preparing for the final weld. The inward movement of the alidade support towers provided an excellent check of the design calculations which predicted both the tower deflections and stress in the shaft accurately. The final weld joining the sections was made and erection of the box girder truss surrounding the elevation shaft began.

As may be seen in the photograph, the framework for attachment of the backup structure, feed arm and elevation wheel, directly above and below the elevation shaft is now complete. This acts as a truss and allows the shaft to be self-supporting, so the temporary support tower has been removed, allowing installation of the elevation wheel to commence. When complete, the 140x163x40 feet deep box structure will act as the support for the reflector, feed arm and elevation wheel.

The forward half of the elevation box structure has been completely trial erected on the ground and will soon be installed on the antenna. The rear half of the box structure is now in trial erection. The box will be lifted in large fully welded modules to facilitate erection. The first sectors of the elevation wheel keel plate are in place, including several of the 100 feet long spokes, the elevation drive bogies and the stow pin assembly.

A jig for assembling the reflector backup structure trusses has been built on the site. The jig is approximately 175 feet long and 40 feet wide. It is used for assembling the large trusses "on the flat" while maintaining the critical surface curvature. At the time of writing, the center truss was nearing completion on the jig. As the trusses are completed, they will be lifted off the jig and placed on the large concrete erection pad adjacent to the telescope site where the entire reflector backup structure will be constructed.

Other recent progress includes the completion of the actuator equipment room, including electrical installation and air conditioning. NRAO personnel have been able to outfit the room with equipment used for controlling the actuators. Construction of the feed/receiver room including installation of the interior walls, insulation and the feed turret is also underway.

During 1996, the elevation structure will take shape and the overall structure will begin to take on the aspect of a radio telescope. The elevation wheel and box structure will be erected around the elevation shaft. The segments of the box structure above the el shaft will be installed alternately to maintain balance in the tipping structure. The bull gear segments will be attached to the wheel, along with the counterweight boxes which will be filled with concrete in a pre-determined order to keep the structure balanced and "tail heavy". If the weather allows construction to proceed during the winter months, this part of the erection will be completed in March.

The assembly and trial erection of the reflector back-up structure (BUS) will continue throughout the remainder of 1995 and into the first half of 1996. The horizontal feed arm is scheduled to be installed on the antenna by the end of the first quarter, as well. Once the horizontal feed arm and portions of the lower vertical feed arm are successfully installed, erection of the BUS on the antenna may begin. The BUS modules will be disassembled from the trial erection pad and lifted into place on the antenna. This trial disassembly and installation on the structure will occur from February through November 1996.

Preparations have been made for the trial erection of the upper 60 feet of the vertical feed arm at Green Bank. During 1996, this assembly will be used for final setting of the subreflector surface and testing and calibrating all mechanical elements on the feed arm including the prime focus boom, the prime focus feed rotation mount (FRM), the subreflector adjustment mechanism, the turret in the feed receiver room and the entire feed arm servo. If possible, the entire assembly will be installed as a unit on the telescope following this extensive testing.

The main reflector panel installation will begin in November 1996 and carry through until completion in June 1997. The final alignment and test of the antenna will occur during June and July 1997 with antenna delivery scheduled for early August.

Servo

NRAO's responsibility with respect to the GBT servo involves monitoring the progress of the servo contractor. This entails reviewing schedules, test procedures and other documents. It also involves witnessing tests of various subsystems and evaluating the results. Finally, it requires the clarification of requirements and specifications as the design process evolves. The Contractor is providing two servo systems for the GBT, one to control the AZ/EL motion (AZ/EL servo) and a second to control motion of various components near the tip of the feed arm (Feed Arm Servo). NRAO also has the responsibility of assuring that the servo system will be suitable for high frequency (>50 GHz) operation of the GBT, even though the contract with the Contractor specifies a 15 GHz instrument.

Several major accomplishments were achieved during the past year. The factory testing of the AZ/EL servo was completed. This involved a thorough test of both the hardware and software, and included everything but the antenna itself (the antenna position was simulated by integrating the tach feedback from the drive motors.)

The design of the Feed Arm Servo was completed.

A plan for calibrating the subreflector mechanism, as part of the plan to enhance the tracking capability of the GBT, was designed. A contractor, a consultant, and internal staff who would implement the plan were identified.

The pointing of the "as-delivered" GBT was studied by consultants and NRAO staff. The behavior of the RF beam on the sky in response to various pointing commands was studied using a detailed model of the telescope. This has been referred to as the "dynamic analysis". Using this model, software enhancements will be implemented in 1996 which assure the high frequency performance of the telescope.

Plans for 1996 will include completion of the design and the factory testing of the Feed Arm Servo. NRAO will review and critique the test procedure and witness the testing.

In addition, field testing of the Feed Arm Servo will be conducted in Green Bank. For this test, the servo and associated mechanisms will be mounted on the tip of the feed arm, before the arm is lifted onto the structure.

Measurement and fine setting of the subreflector surface also will take place during 1996. Calibration of the subreflector positioning mechanism will also be performed. Photogrammetry will be used to measure the position of the subreflector at various command orientations. These positions will be analyzed by software supplied by a consultant to arrive at refined equations of motion.

Remaining portions of the AZ/EL servo will be delivered to Green Bank, and final installation will begin.

Schedule

“Program Plan 1995" reported the Contractor’s delivery date for the GBT as the end of 1996. Over the ensuing year, complications in fabrication and erection of the complex tipping structure have led to an additional delay. Fortunately, however, as also reported in “Program Plan 1995", NRAO has developed a plan to absorb the cost of this delay through a program of personnel transfers and technical program review. The additional project delay, from late 1996 until mid-1997, can be covered under the same program.

In January 1995, a carefully planned transition of NRAO employees was begun in order to move personnel from the construction project budget to operations budgets. This transition allows the necessary build-up of operations staff at the Green Bank observatory in anticipation of completion and commissioning of the GBT. In addition, following a rigorous review of the in-house technical programs, the decision was made to halt development of the active surface autocollimator and floodlight systems and to postpone the development of the 40-52 GHz receiver. Also, in early 1995, a review of the entire cost structure of the GBT was carried out to provide an accurate, precise budget for the remainder of the project. These actions yielded a collective project contingency of slightly over $1 million. This contingency will be used to offset the cost of the additional schedule delay.

It is anticipated that through careful interface with the contractor and use of the 140 Foot Telescope as a test bed, the commissioning phase will begin sooner and possibly be shortened from approximately one year to possibly three to six months.

System Integration

During 1995, the scope of integration of GBT systems at the 140 Foot Telescope was expanded and organized to include major subsystems of Monitor/Control, Data Analysis, and Electronics in order to evaluate the performance of these systems working together. The Electronics systems put in place at the 140 Foot Telescope now include three GBT front-ends, the GBT Continuum backend, and the upgraded Spectral Processor, and additional subsystems are being phased into use. The AIPS++ project has provided significant resources to support this integration effort, providing the data analysis tools used to manipulate and display continuum and engineering data acquired by the Monitor/Control system. The integration effort is organized to first emphasize the performance of astronomical observations of the types which will be needed during the commissioning and early use of the GBT, moving from basic continuum observations toward spectroscopy, holography, pulsar, and VLBI. This effort allows GBT developers to evaluate their designs working in conjunction with the systems of other groups, in the real world environment of a working telescope, and while being used by observers and telescope operators. This effort will extend into 1996 with the addition of other subsystems and observing capabilities. Additional integrated tests will be utilized as deemed necessary.

During 1996, significant effort will go into planning the outfitting and the commissioning of the antenna. The on-the-ground outfitting of the actuator control room has already been completed, and similar outfitting of the receiver room is expected to begin in January. We will coordinate the purchasing of cabling, the installation of equipment on the antenna, and the schedules of the various NRAO groups in order to ensure that the GBT is ready for use as soon as possible after the antenna delivery.

Electronics

Over the last 12 months many of the GBT subsystems have been designed and or integrated/tested at various locations around the site. In particular, the 8-10 GHz, 12-15 GHz, and 18-26.5 GHz receivers have been installed on the 140 Foot Telescope and their critical parameters are being monitored and logged continuously. An X21 multiplier and LO distribution module has been designed, built and tested and will serve as the third LO in the oscillator chain. A phase-monitored fiber optic LO reference distribution system has been designed and fabrication is 80% complete. The weather station was installed. Temperature, dew point, barometric pressure, wind speed and wind direction are being continuously recorded. A Site Timing Center is operational and includes subsystems for precise time such as a Maser, GPS receiver, IRIG-B time distribution system, 1PPS distribution and phase measurement system. Each of these subsystems are being monitored and logged continuously. The Digital Continuum Receiver was integrated with the Monitor & Control System on the 140 Foot Telescope and is presently under going tests. The design of the spectrometer was completed and construction begun. Enhanced performance for the system in supporting pulsar observations was proposed and incorporated into the system specification. Prototypes for the 1024-lag correlator chip to be used in the system were successfully completed.

During 1996 the following progress is planned:

The 1.7-2.6 GHz receiver, 40-52 GHz receiver and the GBT tertiary mirror will be designed in 1996 and construction will begin.

The Prime Focus receiver and the design/construction of the feeds of the three lowest frequency bands will be completed.

The design of Prime Focus receiver #2, including the 910-1230 MHz band will begin.

The GBT holography receiver will be further tested to investigate its performance and the entire system temperature.

A second IF Converter rack and most of the Analog rack will be constructed. Further tests of the IF system will be done in the lab and at the 140 Foot Telescope.

Design of the GBT control room wiring and cabling will be completed and construction will be started. Design of the wiring and cabling on the GBT will be completed.

Outfitting of the receiver room will take place, on the ground.

The weather station will be fully operational with all instruments calibrated to the specified requirements.

Construction and preliminary testing of the spectrometer system will be completed. The remaining correlator chips required should be completed. Software support, both for the embedded microprocessors and for the system VME computer, have a high priority in 1996. Shipment to Green Bank after completion of stand alone testing in Charlottesville should take place in the second quarter. On-site testing and integration into the GBT system will start upon its arrival in Green Bank.

Monitor and Control

The past year has witnessed the completion of operational software systems for the site timing center, weather station, spectral processor, 140 Foot Telescope, and Cassegrain receivers; of coordinated control of the DCR, spectral processor, antenna, and registries (producers of data associated parameters); of production of FITS files for backend data, logs, and data associated parameters; of a Console GUI rewrite to give it an improved "look and feel"; of the message system;

of the Solaris port; of the control of monitor and control systems from Glish; and of the development of the basic analysis and algorithms for controlling the active surface (best fitting parabaloid) and Gregorian optics.

Besides applying the basic monitor and control software to further devices, e.g., holography and LO, the following tasks are scheduled to be worked on in 1996:

Panel Gateway - design and implement a system for the M&C LAN/site LAN gateway machine which: (1) allows the operator to control all network access to the GBT, (2) buffers I/O to GBT Managers so clients' performance (e.g., Consoles and Glish) cannot affect the Managers, and (c) minimize Internet traffic by passing the minimum information needed by remote clients.

Observing Frequency Formula - design and implement a system to define or verify the IF's observing frequency formula by equation, matrix, or component settings.

Setup DAP - save defining setup Parameters for each scan into a FITS file as data associated parameters.

Simulator - define and design an approach to simulation of the telescope control system to allow observer verification of observing runs and instruction of telescope operation.

IF Emulation - design and implement enhancements to the Console to emulate and display IF signal characteristics.

On-demand Logging - implement the selection and control of monitoring points for temporary logging.

Error Logging - implement the logging of specified monitor points dependent on error states.

Task Independence - enhance libraries so that programs on the Suns or single-board computers may be restarted or initialized independently. This includes shutting down gracefully upon receiving a termination signal.

Watchdog System - design and implement a system to detect failure of any task in the GBT system.

Glish Accessor - implement a Glish client for interfacing to the Accessor to allow users to read any monitor point and to generate streams of monitor values as Glish events.

The central theme to the development is not the ability to write a system that can control a telescope but rather to build a foundation on which features may be added that provide all the information and control the observer needs to do good science. Some of these features will be tested during 1996.

Open Loop Active Surface

During the last 12 months, several tasks have been accomplished in the Open Loop Active Surface project. The actuator control room has been outfitted with everything that can be installed while the room is on the ground. This includes mainly mechanical and electrical furnishings.

A cable tester for evaluating all the actuator cables has been selected and purchased. Work is about 50% complete towards integrating it into a cable/actuator testing system. A total of 52 control panels, which contain the actuator control modules required to control all 2209 actuators, were built and tested. A test was set up and run to evaluate the effect of one million start/stop cycles on the actuator motors. The number one million was selected based on operational requirements of the actuator. It was shown that the bulk of the wear on the motor brushes is due to the number of mechanical rotations of the motor; only a small amount is due to the number of start/stop cycles. During the above test, it was found that grease migrated from the actuator gear box into the motor. Causes of and solutions to this problem were investigated. The solution taken was for NRAO to remove excess grease from all actuators manufactured to date (approx. 1800) and to replace bearings in motors that appeared to have been affected by grease migration. The vendor has modified the procedure for greasing the gear box on the final 600 actuators. This provided a good opportunity for NRAO to test each of the actuators received.

Detailed system and software requirements were written in order to organize the design of the control software. Rudimentary software is now in place to control and monitor all actuators.

The order of 2400 actuators was completed. Actuator power supply turn-on transients were found to be larger than expected and were suspected of causing damage to several motor drivers. Circuits to keep the transients in an acceptable range have been designed.

During 1996, the power supply transient monitoring circuits will be built and tested. In addition, NRAO will complete the cable test system for the actuator cables and all software which controls and monitors the 2209 actuators, will be completed and tested. Additional software will be used to monitor various devices related to actuator control.

Circuitry required to monitor specific parameters related to actuator control will be designed, built and tested. All cables and actuators will be tested after installation on the structure. The software interface to the 3D Surface Designation System (the higher level system that controls the active surface) will to be tested.

Closed Loop Active Surface and Laser Pointing

Progress on the electronic distance measurement hardware and software has continued during 1995. The Green Bank machine shop production of the first six mirror units was on schedule, and the remaining seventeen units will be complete by the end of the year. All control panels have been completed, tested, and crated awaiting installation on the GBT. All laser modulators are complete and the laser detectors will be finished by the end of the year. The panel retroreflectors and mounts are in Green Bank awaiting assembly and calibration, which will start fourth quarter 1995 and extend into 1996. The University of Arizona Optical Sciences Center delivered two prototype wide angle spherical retroreflectors and complete design drawings. The embedded laser control computer system architecture has been extensively tested with excellent results. With the successful demonstration of moving retroreflector tracking, and a revision of the documentation manual, the embedded control portion of the system will be essentially complete. The patent office has allowed the claims on an application filed in 1994 and the patent number should be issued in 1995.

The GBT system architecture will be finished by the end of 1995. The ground based laser locations have been surveyed, and the arm mounted laser locations will be on the drawings by the end of the year. In 1996, the finite element analysis model of the laser and retroreflector locations and instrument pointing corrections, as a function of elevation, will be complete. Work is underway on the prototype panel setting tool, and the complete unit will be delivered to the Contractor by the end of the year. After approval by the Contractor, the remaining units will be built in 1996.

The 140 Foot telescope demonstration is well underway. This will test GBT laser hardware, software, monument construction, and calibration procedures and techniques. While the first two quarters of 1995 have concentrated on construction and installation of equipment, the remainder of the year will concentrate on calibration and software testing---including tracking moving retroreflectors for the first time.

In 1996, attention will move from instrument hardware production and the embedded control system software to the GBT system architecture and calibration methods. Software design will begin interfacing with the monitor and control active surface and precision pointing groups. The 140 Foot Telescope demonstration will continue to operate and serve as a prototype for all GBT hardware, software, and calibration procedures. Actual hardware location and cable detail drawings will be generated in preparation for the contractor granting access to the structure and surrounding site. Instrument enclosures will be designed and built. Spherical retroreflectors will be located on the structure drawings and mountings will be designed. The spherical optics will be purchased and mounted in the calibration lab. The calibration lab workload will increase in support of the panel retroreflector mounting and instrument system final assembly. A number of calibration jigs and fixtures will be built. Extensive documentation of the system hardware, software, calibration, and operations will be generated.

GBT Data Analysis

The 140 Foot Telescope GBT integration tests in July 1995 successfully demonstrated control of the 140 Foot Telescope and the DCR digital continuum receiver using the Glish command line interpreter. Standard pointing observations were taken and analyzed using AIPS++ routines from Glish. During 1996, it is planned to extend the functionality and ease of use of both AIPS++ and Glish for GBT telescope control and data analysis. All data analysis software needed for the acceptance of the GBT should be available by the end of 1996. This will include standard telescope pointing analysis as well as holography.

Other major areas of development will include data archiving of both observational data and telescope monitor data. The use of FITS binary tables for all archive data insures compatibility with the astronomical data standard. Having data in a standard format makes it possible to process GBT data using several data analysis systems in addition to the AIPS++ system. The operational aspects of GBT data taking and archiving will be fully developed during 1996, using the 140 Foot Telescope as a testbed.

Pointing

Several areas will be addressed by the Precision Pointing group during 1996. Of particular interest are the Focus-Tracking Module, the interface with the active surface, the calibration of the subreflector motion, and the review of the astronomical algorithms used in the Monitor and Control system.

The heart of the GBT positioning problem is in two stages. First, the principal axis of the primary must be directed toward the source of interest. Second, the optics, either the prime focus feed or the combination of Gregorian mirror and secondary feed must be positioned to achieve optimum gain and purity of polarization. The first stage will be accomplished in Phase I using an algorithm which models the various components of the systematic, repeatable pointing errors. This algorithm which has already been installed in the Monitor and Control will be augmented in later phases by measurements from components of the precision pointing system such as the laser rangers and the quadrant detector. The effort in the second stage during the next year will de directed toward the development of the Focus Tracking Module which commands the location of the prime focus feed and the Gregorian subreflector. Development of the programs which describe the structure of the telescope and which calculate by ray-tracing the optical path has proceeded well. These programs will be used to estimate the motion required as a function of telescope attitude in order that the GBT remain focussed.

In Phase II the figure of the surface will be determined by the positioning of the actuators. The commanded position will be deduced from the structural model of the telescope. Since the optimal position for the telescope optics requires knowledge of the figure of the primary mirror, the Precision Pointing group will work with the Active Surface group during 1996 to develop the programs to command the actuators to drive the requisite distance to attain the desired surface figure. A program which computes the positions the actuators should be set at as a function of telescope attitude, in order that the desired surface be achieved, will be completed.

One of the uncertainties in the design of the Gregorian Focus-Tracking Module is the actual displacement of the mirror corresponding to the motion of one or more of the six actuators on which the mirror is mounted. The complicated problem of the calibration of the mirror mounting is similar to the calibration of certain Stuart Platforms, a problem which has been discussed in the literature of mechanical engineering and robotics. The calibration of the GBT system will begin with an extensive study when the mirror has been received in Green Bank in early 1996. The planning for this measurement has already begun. It is expected that these calibrations will be sufficient to provide the capability to position the subreflector in Phases I and II. In the later phases it will be necessary to update the initial ground-based calibration with a series of measurements using the GBT itself. The design of the system for calibration in the later years will begin in 1996, following the completion of the ground calibration program.

In a related study, an effort will be made to model the effects of observational errors on the calibration of the position of the subreflector, in order to better understand the precision with which in situ calibration can be performed, and to explore which observational techniques will be most useful. The study will be based on Monte Carlo simulations.

The Monitor and Control system will need to use the most precise algorithms available in order to calculate the customary corrections to be applied to the astronomical coordinates. The accuracy of the codes for precession, aberration, and nutation will be verified. The calculation of atmospheric refraction must be made to a higher accuracy than has been generally true in the past, and efforts are in progress to specify a suitable algorithm. Routines for tracking objects moving at other than sidereal rates, and for the generation of ephemerides for planets, planetary satellites, and comets, will be developed during 1996.