METROLOGY SYSTEM FOR THE GREEN BANK TELESCOPE

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The National Radio Astronomy Observatory (NRAO) is constructing a 100-meter aperture, 60-meter focal length offset paraboloid, fully steerable, radio telescope in Green Bank, West Virginia. The Green Bank Telescope (GBT) will be the world’s largest fully steerable telescope when completed in late 1999. The GBT stands 150-meters at its peak and has a moving weight of 8000 tons suspended on 16 conical steel wheels on a 32-meter radius track. The goal is to obtain a reflector surface accuracy of 0.25 mm RMS and a pointing accuracy of 1 arcsecond, under benign weather conditions, in order to work up to a frequency of 100 GHz (3 mm wavelength). To accomplish this goal, a number of unique features are included in the design of the GBT. The surface is composed of 2004 reflector panels mounted on motor operated actuators to correct the surface for thermal and gravity deflections of the support structure. Custom designed and automated Electronic Distance Measurement (EDM) instrumentation is included to provide closed-loop feedback of the surface shape at the 2209 actuator locations, and measurements from fixed ground-based instruments provide closed-loop measurements for pointing error corrections. Six instruments are mounted on the structure above the main reflector looking into 2209 retroreflectors mounted on the surface, to produce a complete survey of the reflector every 8 minutes. Twelve ground-based instruments, equally spaced on a 120-meter radius around the telescope, track retroreflectors mounted on cardinal points on the telescope structure. The two systems are tied into a survey network referenced to the 12 ground-based instrument monuments. The instruments use a laser diode modulated at 1500.000 MHz and a digital phase measurement technique to produce a measurement modulo 100 mm. A servo-controlled mirror is used to switch between targets. The instrument accuracy is around 0.100 mm at 100 meters (1 ppm) with a measurement speed of 5 points per second for near neighbor retroreflector targets. All coordinates are calculated by trilateration, i.e., only distances are used in the reduction. The group refractive index, the major limit to accuracy, is corrected by a combination of refractometer paths between ground monuments; temperature, pressure, and humidity profile measurements; and possibly acoustic thermometry. For example, a 1°C change in temperature produces a 1 ppm change in the group refractive index—the entire error budget if uncorrected. The 18 instruments are interconnected via Ethernet to a central computer that orchestrates the required measurements and computes the coordinates. The central computer tracks the telescope motion from 24-bit encoders and a finite element analysis model of the structural deformations as a function of telescope elevation angle.

These measurements will be used in the early stages to study deflection of the structure and refine the finite element analysis model. In operation, the measurements will be used to correct the surface shape and absolute pointing.

Key Words: electronic distance measurement, retroreflector, Green Bank Telescope.

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1 http://info@nrao.edu
4 D. Wells, “Visualizing the Geometry of the GBT Metrology Systems,” NRAO GBT Memo #177, February 25, 1998; Figure 2.
5 A.L. Petticrew, “Laser Rangefinder Deflection Measurements of the GBT Derrick,” NRAO GBT Memo #160, November 18, 1996; Figure 5; D.H. Parker, “First Measurements of the GBT Feed Arm,” GBT Archive #L0535, July 29, 1999.
INSTRUMENT SPECIFICATIONS

- **Model**: PSH97
- **Absolute Accuracy**: 50 µm + 1 ppm
- **Differential Accuracy**: 5 µm + 0.2 ppm (no group refractive index correction)
- **Maximum range**: ≈1 km (3” retroreflector, fair conditions)
- **Phase Ambiguity**: modulo λ/2 (=100 mm)
- **Phase Accuracy**: 0.01° (3 µm)
- **Sampling**: 16 bit, 64 kHz, DMA, trigger synchronized to LO
- **Measurement Integration Time**: 1-1000 ms (128 ms typical)
- **Radiation Source**: amplitude modulated laser diode
- **Power**: 10 mW
- **Wavelength**: 780 nm
- **Beam Size**: 3 x 3 mm
- **Beam Divergence**: ≈0.4 x 0.4 mrad (fwhp)
- **Detector**: PIN diode
- **Signal Level Range**: 0.030-10.0 V
- **Frequency Reference**: 100.000 MHz rubidium
- **Amplitude Modulation (CW)**: 1500.000 MHz
- **LO Frequency**: 1500.001 MHz \(\phi\) locked to modulation + IF
- **IF**: 1 kHz
- **Weight**: 150 lbs
- **Instrument Dimensions**: 43” x 16” x 16”
- **Mount**: Kelvin clamp
- **Mirror**: dual axis, closed loop servo
- **Panel Measurement Rate**: 5/s
- **Encoders**: 100,000 count, incremental

EMBEDDED CONTROL SYSTEMS SPECIFICATIONS

- **Bus architecture**: ISA (PC/AT), 8 slots
- **Power**: 120 VAC, 3 A
- **Servo control**: dual LM628 PID
- **Servo amplifier**: pulse width modulated (20 kHz)
- **Control Panel Dimensions**: 42” x 24” x 8”
- **Embedded Computer**: 286 PC (minimum)
- **Operating System**: DOS
- **Time Sync**: IRIG
- **Interface**: Ethernet

GBT OPTICAL METROLOGY ARCHITECTURE

- **Panel Retroreflectors**: 25 mm, BK7 glass corner cubes, total internal reflection
- **Spherical Retroreflectors**: cat’s eye, 35 mm entrance pupil, ± 60 degree acceptance angle
- **Panel Retroreflectors**: 2209
- **Spherical Retroreflectors**: 19
- **Cardinal Points**: 42
- **Ground Instruments**: 12 equally spaced on 120 m radius
- **Tipping Structure Instruments**: 6
- **Monument Baseline Accuracy**: ≈100 µm
- **Monument Construction**: 4 foot φ concrete, 15 feet long, undisturbed soil, cased below freeze line
- **Data Adjustment method**: least squares trilateration (using distances only)
- **Refraction Correction**: combination of ground based refractometers, weather stations, meteorological model, and possibly acoustic thermometry
**Figure 1**
The GBT construction progress as of 7/28/99. All major structural steel has been erected. Estimated completion date is late 1999.

**Figure 2**
A schematic diagram of the metrology system with 12 fixed ground instruments, 6 instruments on the feed arm, retroreflectors at cardinal structural nodes and panel actuators.

**Figure 3**
A PSH97 Instrument. Note the servo controlled mirror (on the right side) used to direct the beam to selected targets.

**Figure 4**
A Spherical Retroreflector built by the University of Arizona.

**Figure 5**
A plot showing deflection of the derrick tower while lifting a 45-ton load. Note this was at a distance of 725 meters from a test range.
Figure 6
Data taken from a ground instrument to a target on the tip of the feed arm.
Note the oscillations riding on the gentle motion of the structure.

Figure 7
Expanded section of Figure 6 showing the oscillation of the feed arm at the natural frequency.