RECEIVER AND OPTICS DESIGNS FOR THE 100-METER GREEN BANK TELESCOPE

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ABSTRACT

A 100-meter diameter, fully steerable, offset dual reflector radio telescope is under construction at the Green Bank, West Virginia facility of the National Radio Astronomy Observatory (NRAO). Significant performance improvements are expected of the offset design over that possible with symmetrical antennas. The antenna will be capable of operation from below 300 MHz to above 40 GHz. To take full advantage of the offset design, ultra-low-noise cryogenic receivers will be constructed and installed. This paper will summarize the trade-offs made in the design of the microwave optics, and describe plans for receivers and associated equipment.

INTRODUCTION

In November 1988, the 300-foot diameter transit telescope at Green Bank collapsed and was a total loss. Shortly thereafter, the design of a replacement instrument was started. In July 1991, on-site construction of the foundation for the new antenna began. The new telescope, known as the Green Bank Telescope (GBT), is scheduled for completion in late 1994. This paper will review the work that has gone into the design of the microwave optics and outline plans for microwave instrumentation.

The GBT will be a fully offset dual reflector antenna with a projected aperture diameter of 100 meters, making it the largest offset reflector antenna in the world. The antenna uses an elevation over azimuth mount and the moving weight will be approximately 12 million pounds. The main reflector will be comprised of over 2,000 aluminum panels mounted on approximately 2,200 motorized actuators. Using these actuators to provide real-time correction for gravitational deformations, it is expected that a surface RMS accuracy of better than 450 micrometers will be achieved, making the antenna useful to above 40 GHz. A real-time measurement system based on laser ranging techniques [1] is under development at NRAO which could extend the frequency range to 90 GHz under benign environmental conditions. An 8-meter diameter, Gregorian subreflector with 100 micrometer RMS surface accuracy will be used above 1.15 GHz. For prime focus operation, an appropriate feed and receiver can be placed at the focus, using a retractable arm.

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MICROWAVE OPTICS

The main reflector of the GBT is an offset portion of a paraboloid having a 60-meter focal length, with a completely unblocked projected aperture of 100-meter diameter. Several considerations went into the decision to adopt an offset design rather than a conventional, circularly symmetric antenna. Two features of the offset reflector, the absence of blockage in the aperture and the elimination of spectral reflections between the feed and reflector [2], were deemed significant advantages. These lead to higher efficiency, lower sidelobes, less susceptibility to RFI, lower system temperature, and better spectral baseline stability. Once it was determined that a structural design was feasible at an acceptable cost, the decision was made to adopt an offset design.

Of serious concern was the depolarizing effect inherent in offset reflectors when fed by a purely linearly polarized feed from the prime focus [3], but this can be corrected at the secondary focus by proper design of the subreflector [4]-[7]. This reason, along with the higher efficiency and lower noise obtained at the secondary focus, led to an effort to minimize the frequency at which changeover from prime focus to secondary focus operation occurs. It has been shown in the literature [8] that the subreflector must be more than 25 wavelengths in diameter, in order to correct for the depolarizing effect. Cost and practical considerations led to the choice of an 8-meter diameter subreflector. Consequently, the changeover frequency between prime and Gregorian focus receivers occurs at approximately 1.15 GHz.

Various electromagnetic analysis techniques were used to study the performance of several proposed configurations. Sidelobe levels, spillover characteristics, cross-polarization levels, efficiency, feed size, and other performance measures were used to select the focal length, amount of offset, subreflector type, and location of the secondary focus. Figure 1 shows a view of the reflectors in the plane of offset.

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MICROWAVE RECEIVERS

The microwave receivers and feeds are located near the end of a 60-meter long arm which also supports the subreflector, as shown in Figure 2.

The prime focus receiver mount is located at the end of a 7 meter long boom that can be deployed in front of the subreflector. The receiver, in a weatherproof, temperature controlled enclosure, will be attached to this mount and when deployed will place the feed at the paraboloid focal point. Plans call for construction of prime focus receivers and associated feeds covering 290 to 1230 MHz in five bands, each with 1.35:1 bandwidth.

A 430 square foot temperature controlled room will be located at the secondary focus, to house the Gregorian receivers and associated equipment. A rotating turntable, fourteen feet in diameter, will form part of the ceiling of this room and the feeds and cryogenic receivers will be attached to this turntable. The feeds will be located about a 56 inch radius circle, any point of which can be brought coincident with the secondary focus. Plans have been developed for fifteen receiver bands that cover 1.15 to 52 GHz with instantaneous bandwidths ranging from 1.25:1 to 1.5:1. Figure 3 illustrates the turntable with a complement of feeds installed.

Each prime focus or Gregorian feed will connect to a dual channel, cryogenically cooled receiver that will extract and amplify orthogonal polarizations. The technology used will be similar but not identical to that developed at NRAO during recent projects, including the VLBA [9]. The output of each feed will connect to the cooled receiver through a vacuum window constructed of low-loss polystyrene foam. A section of gapped circular waveguide, forming a thermal barrier, will then connect to a waveguide device (polarizer) that separates the two polarizations. The two polarizer outputs are then amplified using ultra-low-noise HFET amplifiers (LNA). The polarizer and LNA are cooled by a closed-cycle helium refrigerator.

Following the cryogenic portion of the receivers, the signals will be amplified and converted to an IF in the range of 0.1 to 8.0 GHz and transmitted over fiber optic cables to a control center. Figure 4 shows a simplified block diagram of a typical receiver. At the control center various types of equipment will digitize and store the signal, depending on the type of observation.

The receiver designs will emphasize low-noise performance, stability, and reliability. In order to cover the broad frequency range of the antenna with as few receivers as possible, large receiver bandwidths are desirable. The components that limit the achievable bandwidth are the feed, polarizer and LNA. Feed and LNA design and construction will be done at NRAO, and the polarizers will be either purchased from commercial vendors or developed internally, depending on the frequency range. Table 1 shows the receiver (Rx) frequency bands selected to provide continuous coverage from 0.3 - 52.0 GHz. Also given are the bandwidth (BW) ratios and the expected receiver noise temperatures (T_{Rx}).

SUMMARY

The design trade-offs for the GBT antenna have been reviewed, and the plans for receiver instrumentation described. The performance of the antenna is expected to be exceptional, and state-of-the-art, low-noise, cryogenic receivers will be required to take full advantage of the antenna's performance and broad frequency coverage.

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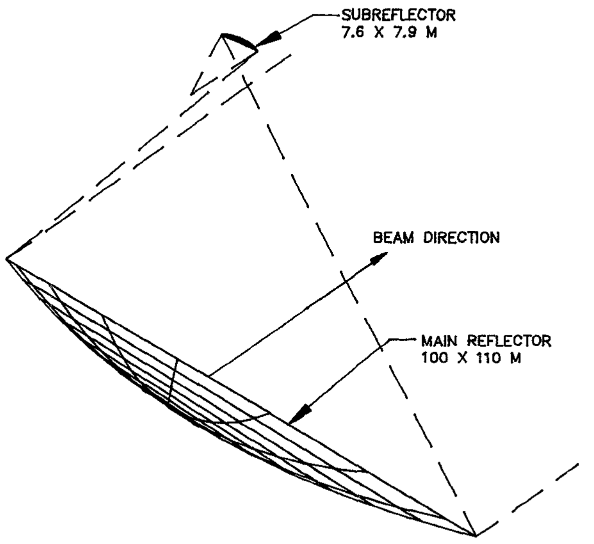

Fig. 1. GBT reflector configuration. The main reflector is an offset portion of a paraboloid with 60-meter focal length. The subreflector is an offset portion of an ellipsoid. The dashed lines indicate edge rays in the plane of the paper. The main reflector projected aperture is 100-meters in diameter and free of blockage.

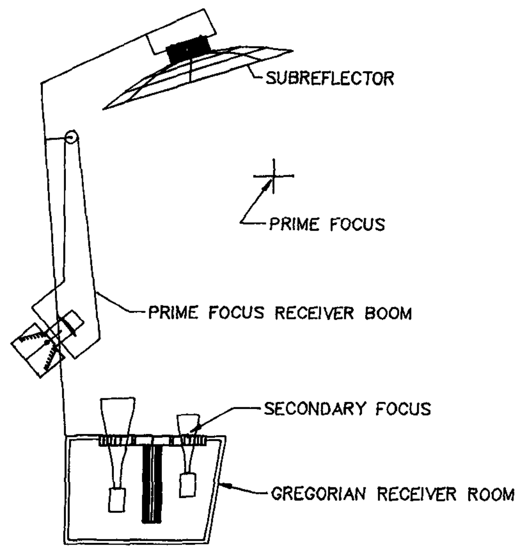

Fig. 2. Detail of area near the subreflector and foci. Multiple receivers are available on a motorized turntable at the secondary focus. For observations below about 1.15 GHz, the prime focus receiver boom can be deployed in front of the subreflector.

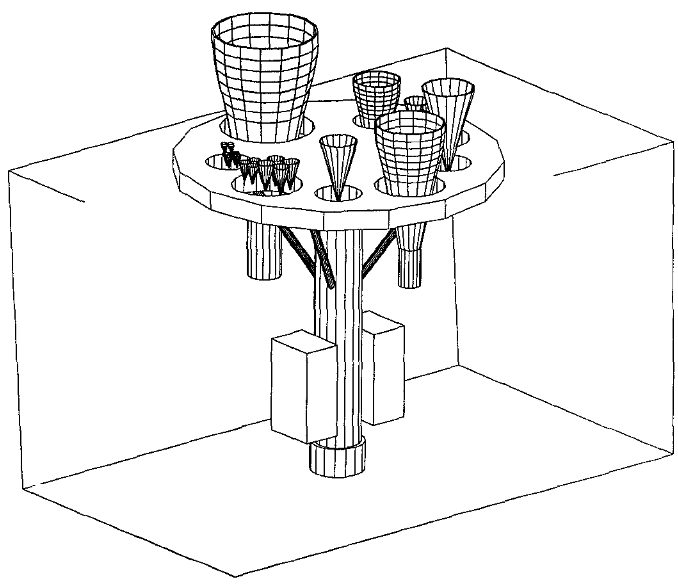

Fig. 3. Conceptual view of the Gregorian receiver turntable loaded with a complement of feeds. The turntable is 14 feet in diameter and has eight holes for mounting of equipment. Feeds are shown to scale, the largest operates down to 1.15 GHz, the smallest to 52 GHz. Note the arrays of smaller feeds; it is expected that feed arrays will be popular on radio telescopes in the future.

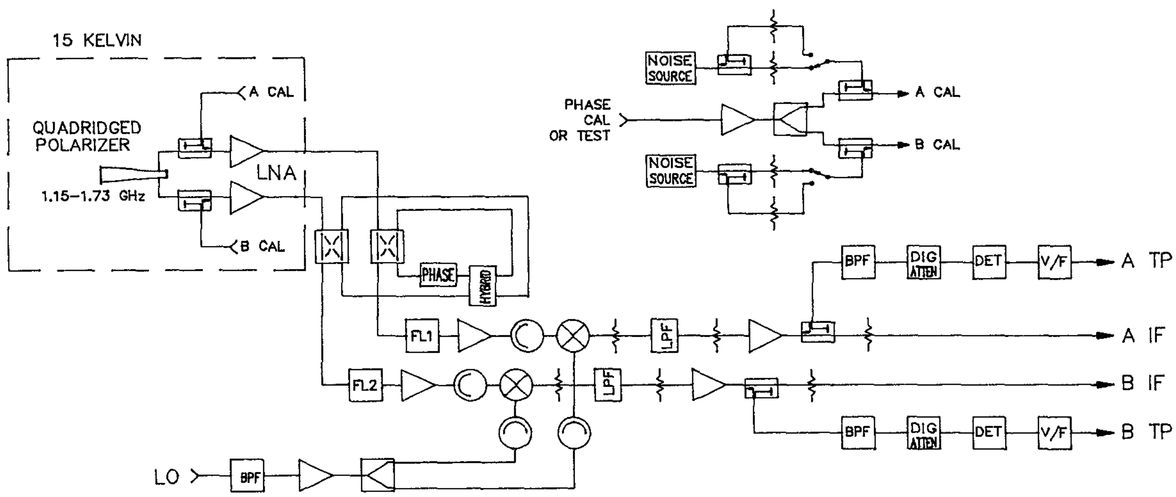

Fig. 4. Block diagram of a typical receiver. The polarizer, calibration couplers, and LNA are cooled to 15 Kelvin by a closed-cycle refrigerator. A single down conversion is used here to an IF in the 100-500 MHz range for input to the recording equipment. Most receivers will require two or more conversions to avoid image problems.

TABLE 1. GBT RECEIVERS

GBT PRIME FOCUS RECEIVERS					GBT GREGORIAN RECEIVERS				
Rx No.	Receiver Band (GHz)	Rx BW (GHz)	BW Ratio	T_{Rx} (K)	Rx No.	Receiver Band (GHz)	Rx BW (GHz)	BW Ratio	T_{Rx} (K)
1	0.290-0.395	0.105	1.36	10	1	1.15-1.73	0.58	1.50	5
2	0.385-0.520	0.135	1.35	10	2	1.73-2.60	0.87	1.50	5
3	0.510-0.690	0.180	1.35	8	3	2.60-3.95	1.35	1.52	6
4	0.680-0.920	0.240	1.35	7	4	3.95-5.85	1.90	1.48	7
5	0.910-1.230	0.320	1.35	7	5	5.85-8.20	2.35	1.40	8
					6	8.00-10.00	2.00	1.25	10
					7	10.00-12.40	2.40	1.24	11
					8	12.00-15.40	3.40	1.28	12
					9	15.40-18.00	2.60	1.17	13
					10	18.00-22.00	4.00	1.22	15
					11	22.00-26.50	4.50	1.20	20
					12	26.50-33.00	6.50	1.25	25
					13	33.00-40.00	7.00	1.21	27
					14	40.00-45.50	5.50	1.14	30
					15	45.50-52.00	6.50	1.14	35