RF Performance of the GAVRT Wideband Radio Telescope (EuCAP 2010)

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***Abstract*— A wideband Radio Telescope was designed and built for use in the Goldstone Apple Valley Radio Telescope (GAVRT) program. It uses an existing 34-meter antenna retrofitted with a tertiary offset mirror placed at the apex of the main reflector. It can be rotated to use two feeds that cover the 0.5 to 14 GHz band. The feed for 4.0 to 14.0 GHz is a cryogenically cooled commercially available open boundary quadridge horn from ETS-Lindgren. Coverage from 0.5 to 4.0 GHz is provided by an un-cooled scaled version of the same feed that uses a cooled LNA. The measured performance is greater than 40% over much of the band.**

I. Introduction

The Goldstone Apple Valley Radio Telescope (GAVRT) outreach project is a partnership involving NASA, the Jet Propulsion Laboratory (JPL), the Lewis Center for Educational Research (LCER), and the Apple Valley Unified School District., located east of Los Angles near the NASA Goldstone deep space communication complex. This educational program currently uses a 34-meter antenna, DSS12, at Goldstone for classroom radio astronomy observations via the Internet. The GAVRT program [1] introduces students in elementary, middle, and high school to the process of science with the goal of improving science literacy among American students. The current program utilizes DSS12 in two narrow frequency bands around S-band (2.3 GHz) and X-band (8.45 GHz) and is used by a training program involving a large number of secondary school teachers and their classrooms. To expand the program, a joint JPL/LCER project was started in mid 2006 to retrofit an additional existing 34-meter beam-waveguide (BWG) antenna, DSS28, with wide band feeds and receivers to cover the 0.5 to 14 GHz frequency bands.

The DSS28 antenna was one of two antennas designed as part of the JPL Antenna Research System Task (ARST) described in [2]. The antenna, shown in Fig. 1, has a 34-meter diameter main reflector, a 2.54 meter subreflector and a set of beam waveguide mirrors surrounded by a 2.43 meter tube. The antenna was designed for high power and a narrow frequency band around 7.2 GHz. The performance at the low end of the frequency band desired for the educational program would be extremely poor if the beam waveguide system was used as part of the feed system. Consequently, the 34-meter antenna was retrofitted with a tertiary offset mirror placed at the apex of the main reflector (see Fig. 2). The tertiary mirror can be rotated to use two wideband feeds that cover the 0.5 to 14 GHz band. The feed for 4.0 to 14.0 GHz is a cryogenically cooled commercially available open boundary Quadridge horn from ETS-Lindgren. The wideband cryogenic LNA has a gain of 35 dB and a noise temperature of 5K over the majority of the frequency band. Coverage from 0.5 to 4.0 GHz is provided by an un-cooled, scaled version of the same feed. The computed performance is greater than 40% over most of the band and greater than 55% from 6 to 13.5 GHz. The actual measured performance was a bit less (~40% over most of the band) because of some mirror misalignments and a worse than predicted main reflector surface RMS. This paper will describe the wideband radiometric receiver front end with emphasis on the feed and optical system.

Fig. 1 The ARST antennas

This paper is a follow on to [3] which describes the RF design of the telescope.

Fig. 2: Feeds and Tertiary Mirror on Main Reflector

II. SYSTEM DESIGN

The complete system involves the reflector, subreflector, tertiary reflector, feed, cryogenics subsystem, low noise amplifiers, noise calibration system, frequency converters, digital spectrometers, continuum signal processing, and monitor and control system. Only the optics design, tertiary mirror, feeds, cryogenics, and LNA will be discussed in this paper. The main parameters of this front-end are the antenna efficiency, η and the system noise temperature, Tsys. The goal was an η of > 40% from 1 to 14 GHz and a maximum Tsys of 55K over the band with 35K at best frequencies.

In order to meet the above Tsys requirement the wideband feed (which has more loss than typical narrow band feeds) needs to be cryogenically cooled, at least for frequencies above 4 GHz. The baseline approach will utilize two feeds, a commercially available feed to cover the 4 to 14 GHz range which is cryogenically cooled and a second feed (a scaled version of the higher frequency feed) which is not cryogenically cooled. However, even though the lower frequency feed is not cooled, the LNA amplifier is cooled.

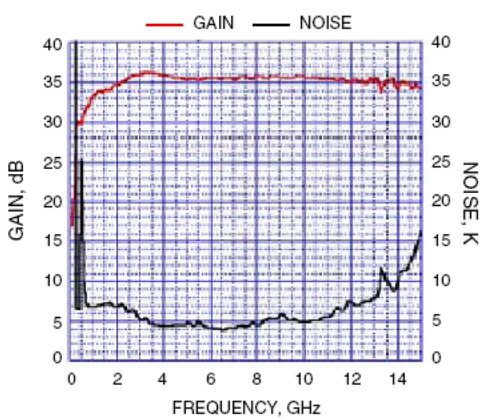

Fig. 3 Wideband Cryogenic LNA

The wideband LNA's required for the system have been under development for many years and over 100 units of the design shown in Fig. 3 have been assembled, tested at 15K, and utilized in radio astronomy and physics research systems. When cooled to 15k, the noise is under 5K from 1 to 12 GHz when driven from a 50 ohm generator.

III. OPTICS DESIGN

The 34-meter antenna was originally designed for high power and a narrow frequency band around 7.2 GHz. The performance at the low end of the frequency band desired for the educational program would be extremely poor if the beam waveguide system was used as part of the feed system. Hence, several redesign options to enable improved performance on the low frequency without the use of the beamwaveguide itself were examined as described in reference [3]. The design chosen was to use an offset tertiary mirror placed at the apex of the main reflector as shown in Figure 2. The tertiary is fed by a commercially available wideband feed from Lindgren [4]. There are two feeds used, one for the lower band and one for the higher band. The tertiary mirror is rotated to switch between the feeds. The high frequency feed (HFF) and LNA with the surrounding Dewar removed is shown in Fig. 4.

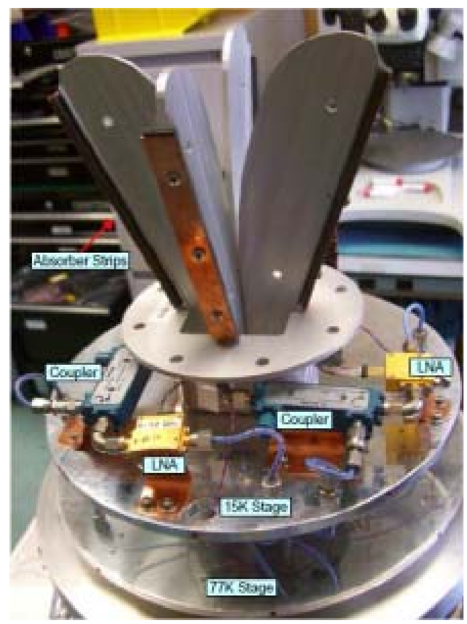

Fig. 4: View of the HFF with surrounding Dewar removed

Amplitude and phase, co-polar and cross-polar patterns of the Lindgren feed were measured at phi angles of 0, 45, 90, and 135 degrees and for theta rotation angles of -180 to +180 degrees in 10 degree steps. This data was then used to optimize the design of the tertiary reflector. Frequencies of 4 and 12 GHz were selected for optimization. The parameters to be optimized were focal length, diameter, offset height, feed tilt angle and feed defocusing. An optimization program was used and the parameters determined that yielded the highest peak gain. Data for the Lindgren feed was take every 50 MHz from 2 to 22 GHz and the calculated performance in the telescope is shown in Figure 5 (although the GAVRT system is only planned to operate over the 4 to 14 GHz band).

A scaled design feed is used for the 0.5 to 4 GHz band and the parabola rotated to point to the second feed position.

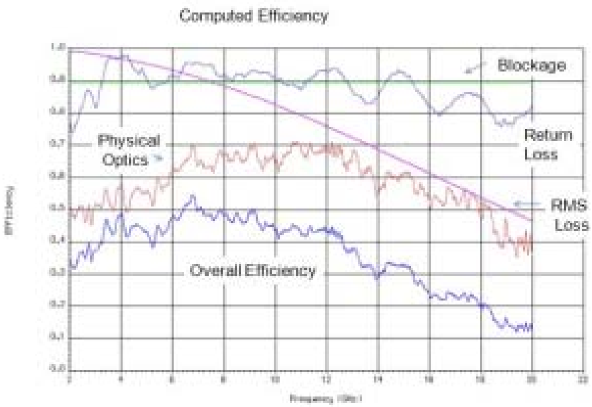

Fig. 5: Computed performance of the HFF showing loss components

IV. Efficiency and Noise Temperature Measurements

The efficiency and noise temperature measurements are described in [5] and will only be summarized here but will include a comparison of the computed results.

The efficiency of the High Frequency Feed was determined by measuring the response of the system to the radio galaxy 3C405 and Venus. The 3C405 measurements were made at an elevation of approximately 23 degrees, while those on Venus were made at approximately 62 degrees. After correcting any pointing offsets by manually peaking the response of the telescope on the source, the telescope was moved off source by one degree in cross elevation. The high power noise calibration signal was pulsed to measure the system gain, and then the telescope was commanded to scan through the source in cross elevation at a fixed rate. Finally, at the end of the scan, the noise source was pulsed again. To process the data, the system gain was estimated from the calibration signal responses using a lookup table to determine the calibration signal value in Kelvin. A Gaussian was then fit to the scan data including a constant offset for the system temperature and a linear baseline to account for drift during the scan. The peak of the Gaussian provided the antenna temperature of the source, and the width of the Gaussian was used to compute the beamwidth. The beamwidth High Frequency Feed measured on Venus and the radio galaxy Cygnus A (3C405) is shown in Fig. 6. The standard rule of thumb for beamwidth is plotted for comparison. Notice that the beamwidth becomes comparable to the angular extent of Cygnus A at around 10 GHz.

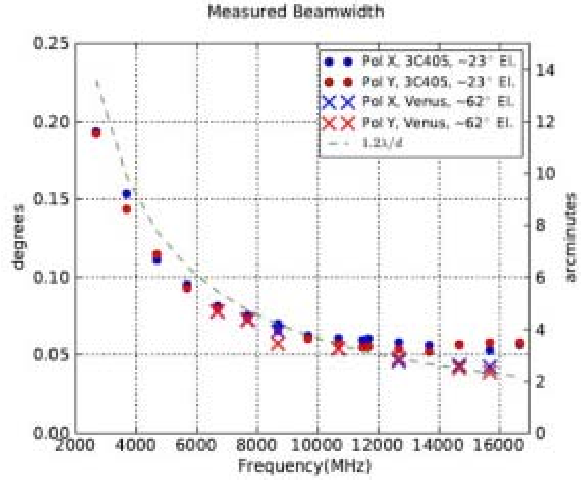

Fig. 6: Beamwidth of the DSS-28 High Frequency Feed measured on Venus and the radio galaxy Cygnus A (3C405).

Fig. 7 compares the measured efficiency of the high frequency feed to the calculated performance. The efficiency data is an ensemble of several sources and several elevation angles. The wide spread in the measured data is primarily due to RFI. There was some misalignment in the tertiary mirror and the effects of the misalignment included in the calculated data. The measured data is in excellent agreement with the calculated data

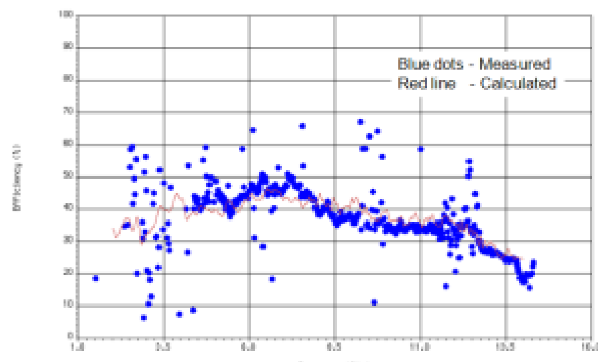

Fig. 7: Comparison of computed and measured efficiency for the HFF

Fig. 8 shows the measured noise temperature of the HFF.

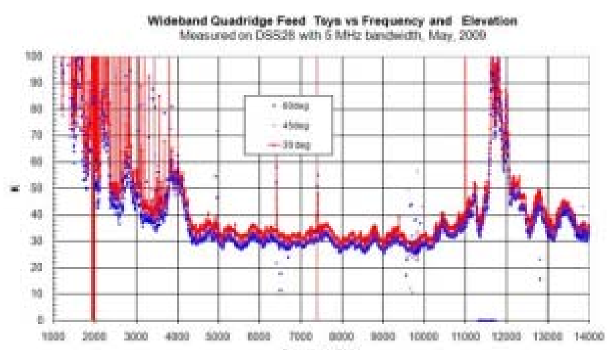

Fig. 8: Measured noise temperature of the HFF.

V. CONCLUSIONS

A 34-meter antenna was retrofitted with a tertiary offset mirror placed at the apex of the main reflector. The tertiary mirror can be rotated to use two feeds that cover the 0.5 to 14 GHz band. The feed for 4.0 to 14.0 GHz is a cryogenically cooled commercially available open boundary Quadridge horn from ETS-Lindgren. The wideband cryogenic LNA has a gain of 35 dB and a noise temperature of 5K over the majority of the frequency band. Coverage from 0.5 to 4.0 GHz is provided by an un-cooled, scaled version of the same feed. The computed performance of the high frequency feed is greater than 40% over most of the band and greater than 55% from 6 to 13.5 GHz. The actual measured performance was a bit less (~40% over most of the band) because of some mirror misalignments and a worse than predicted main reflector surface RMS. The low frequency feed suffers significantly from RFI and the fact that the tertiary mirror is too small for frequencies below 1 GHz. The low efficiency, along with the large amount of RFI present in the lower frequency band make for an uncertain future for the LFF. It should be noted, however, that the LFF should still be quite effective for observing giant pulses from the Crab pulsar because the ux from the surrounding nebula is so great that it will still dominate the system temperature despite the low efficiency.

ACKNOWLEDGMENT

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[1] See http://www.lewiscenter.org/gavrt/

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