A 19 element Cryogenic Phased Array Feed for the Green Bank Telescope

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***Abstract*—A low-noise cryogenic phased array feed (PAF) is in development for the Green Bank Telescope (GBT). The feed consists of electrically small elements tuned to operate near 1.4 GHz and optimized for active impedance matching to cooled front end low noise amplifiers (LNAs). A prototype cryogenic PAF with analog fiber link, down-converters and streaming data acquisition system was recently tested on the GBT. Preliminary results are presented. These efforts form an important step towards the development of a new receiver system, the focal L-band array for the GBT (FLAG).**

I. Introduction

Observatories around the world are engaged in design and development of next generation telescopes with significantly larger collecting area than earlier instruments. Survey speed of these telescopes can be improved by enhancing the field of view (FOV).

One approach to increasing FOV is the phased array feed (PAF). PAFs are dense arrays of electrically small antenna which sample the focal field pattern of a telescope. Multiple beams are formed by phasing signals sampled by the array. Formed beams can overlap, enabling full coverage of the FOV. Phasing can also improve the sensitivity of the telescope. Shaped PAF beams improve the spillover efficiency and reduce the ground noise contribution. Additionally, phasing enhances the illumination of the telescope and thereby increases the effective area. A major hurdle in the design of PAF is the mutual coupling between array elements. Mutual coupling results in the coupling of amplifier noise and modifies element radiation patterns. Detailed electromagnetic, noise and network modeling are needed to design a PAF for radio astronomy applications [1].

Many programs to develop PAF for radio astronomy are in progress around the world. They include the Chequerboard array for Australian Square Kilometer Array Pathfinder [2] APERTIF (Aperture tile in focus) on Westerbork Synthesis Radio Telescope [3], and AFAD (Advanced focal array demonstrator) project of Dominion Radio Astrophysical Observatory [4]. All these projects emphasize on large bandwidth, non-cooled PAF. Currently two projects focus on building cryogenic low noise PAF : FLAG collaboration between Brigham Young University (BYU) and NRAO and AO19 Cryo-PAF being developed by Cornell University and BYU [5].

Focal L-band Array for the Green Bank Telescope (FLAG) is aimed at developing a cryogenic, low-noise PAF to enhance the FOV of the telescope. In this paper, we present preliminary results from the ongoing effort to measure the performance of a prototype PAF receiver on the Green Bank Telescope (GBT).

II. The Green Bank Telescope and FLAG System

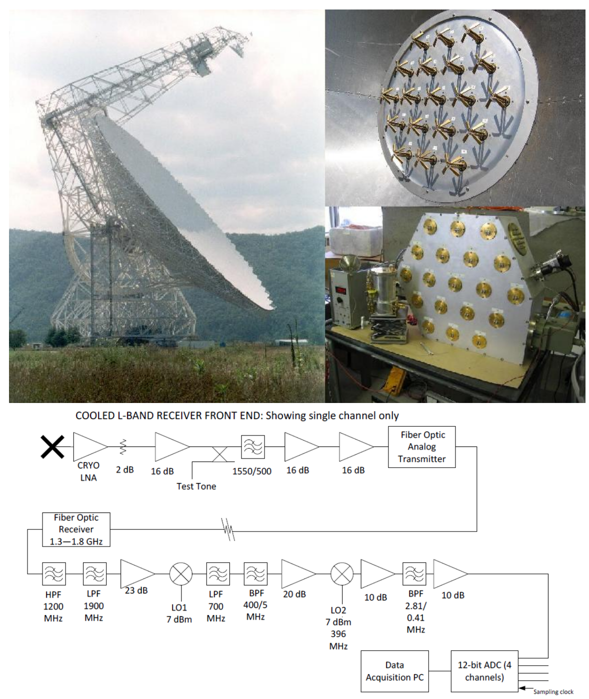

Fig. 1. **Top left:** The Green Bank Radio Telescope (GBT). GBT is an off-axis paraboloid with an aperture size of 100 m. **Top right :** Prototype 19 element dual-polarized “kite” array is shown above and its cryostat is shown below. **Bottom :** A simplified block diagram of the prototype PAF receiver.

The Green Bank Telescope (GBT [6], Fig. 1) is located at the radio quiet zone in Green Bank, West Virginia. The FLAG consists of 19 element dual-polarized dipole array operating near 1.4 GHz (see Fig. 1). The separation between adjacent dipoles is about 12 cm. The array will be located at the prime focus of the GBT during observations. The array elements, designed and fabricated by Karl F. Warnick and a team of students at BYU, are optimized such that the beam-dependent active impedance presented by the elements to front-end amplifiers was close to the amplifier optimal source impedance over the FOV [7]. The measurements presented here are with the version of the element referred to as "kite" dipole. The array elements and balun are maintained at ambient temperature while the LNAs, located in the cryostat (developed at NRAO; see Fig. 1), are cooled to 15 K. The signals received by the dipoles are amplified and band-limited between 1.3 to 1.8 GHz and are fed to analog fiber optic transmitters. The output of the fiber optic receiver is passed through a two stage down-converter. The final IF is 2.81 MHz and the bandwidth at this stage is limited to 420 KHz. The 420 KHz signal is bandpass sampled at the second Nyquist zone using a 12 bit Analog-to-Digital Converter (ADC) and the digitized voltages are recorded. All further processing of the recorded voltage is done offline.

III. Measurements made at the Outdoor test facility, on the 20m Telescope and on the GBT

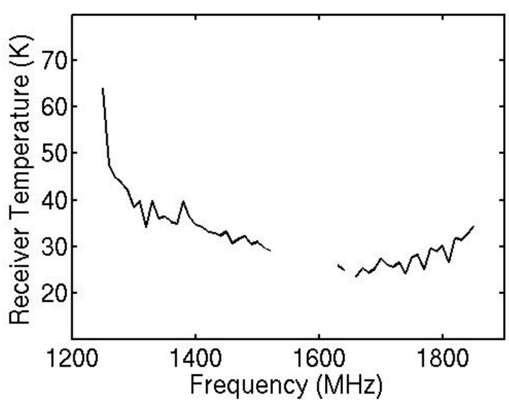

Fig. 2. PAF receiver temperature over frequency. Median receiver temperature of 38 dipoles in the array at each frequency is plotted. At a few frequencies near 1600 MHz, the measurements were affected by radio frequency interference. The measurements were made at the outdoor facility at Green Bank on 14 January 2015.

We used the outdoor test facility at Green Bank to measure the receiver temperature of PAF. An absorber covering the array was used as the 'hot' load and the cold sky was used as the 'cold' load for these measurements. The measured receiver temperature is about 25 K at 1.7 GHz (see Fig. 2). In 2011, the PAF was installed on the 20 m diameter antenna at Green Bank, which has an F/D (F is the focal length, D is the telescope diameter) of 0.4. We observed the astronomical source Cas A (flux density = 1259 Jy at 1.6 GHz). Maximum signal-to-noise ratio beams were formed using this data set [8]. These observations directly provide the ratio T_{sys}/η, where T_{sys} is the system temperature, which is the total noise temperature due to receiver, spillover and emission from the sky and η is the aperture efficiency. The mean value of T_{sys}/η measured on the 20 m telescope was 50 K.

In December 2013, the PAF was installed on the GBT and several observations were made. The F/D of the GBT is about 0.6, which means that there will be substantial ($>$ a factor of 2) ground noise at the output of each PAF element compared to the 20m telescope case. Post-processing the data to form beams with such high ground noise revealed a subtle problem in the receiver system. The measured signal correlations were affected by inadequate image rejection in the down-converters. This problem would have also affected our earlier 20m telescope measurements. The receiver system has now been modified and further tests are planned in the near future.

IV. Further measurements and Future directions

The next round of cryogenic PAF tests using the modified receiver system on the GBT are targeted for early 2015. In the near future, we will also upgrade the system by replacing the analog fiber link and down-converter with a novel digital down-converter and fiber link developed by NRAO [9], and upgraded LNAs are being developed to improve the receiver temperature. A new data acquisition system capable of recording voltage data to disk with a bandwidth of 1 MHz is in progress as well.

Acknowledgement

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