Advanced Multi-beam Spectrometer for the Green Bank Telescope

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Abstract

A new spectrometer for the Green Bank Telescope (GBT) is being built jointly by the NRAO and the CASPER, University of California, Berkeley. The spectrometer uses 8 bit ADCs and will be capable of processing up to 1.25 GHz bandwidth from 8 dual polarized beams. This mode will be used to process data from focal plane arrays. The spectrometer supports observing mode with 8 tunable digital sub-bands within the 1.25 GHz bandwidth. The spectrometer can also be configured to process a bandwidth of up to 10 GHz with 64 tunable sub-bands from a dual polarized beam. The vastly enhanced backend capabilities will support several new science projects with the GBT.

1 Introduction

The Robert C. Byrd Green Bank Telescope (GBT) is the premiere single-dish radio telescope operating at meter, centimeter and millimeter wavelengths [1]. With an off-axis parabolic reflector of size 100 m \times 110 m, the GBT is the largest fully-steerable radio telescope in the world. Its unblocked aperture gives it the sensitivity of a much larger antenna, flat spectral baselines and higher sensitivity to low surface brightness emission. The GBT is located at the National Radio Astronomy Observatory (NRAO)¹ site in Green Bank, West Virginia, USA. It is being used for a variety of unique experiments over a broad range of science.

Since its commissioning in 2000, the GBT's capabilities have been greatly expanded in frequency coverage as well as the instantaneous field of view for observations. The field of view is enhanced using focal plane arrays. The new 4mm receiver is an example of expansion in frequency coverage of the GBT. So far observers have been using all these receivers with an existing spectrometer backend, which has only 3 level sampling, 800 MHz bandwidth and a minimum integration time of one sec. The bandwidth supported by this spectrometer for focal plane arrays is ≤ 50 MHz. Thus the capabilities of the existing spectrometer do not match with those of the new receivers. It is now time to upgrade the backend capability of the GBT.

The National Science Foundation Advanced Technologies and Instrumentation (NSF-ATI) program has funded a new spectrometer backend for the GBT. This spectrometer is being built by the CICADA collaboration – a collaboration between the NRAO and the Center for Astronomy Signal Processing and Electronics Research (CASPER) at the University of California, Berkeley. The new spectrometer vastly enhance the capability of the GBT to support several unique science projects. The projects include mapping temperature and density structure of molecular clouds; searches for organic molecules in the interstellar medium; determination of the fundamental constants of our evolving Universe; redshifted spectral features from galaxies across cosmic time and survey for pulsars in the extreme gravitational environment of the Galactic Center.

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Figure 1: A block diagram of the GBT spectrometer

2 GBT spectrometer design

One of the design considerations for the new spectrometer is to process larger bandwidth (1.25 GHz) with the focal plane array (FPA) receivers. The K-band (18 - 26.5 GHz) FPA of the GBT has 7 feeds. Thus the spectrometer is designed to process 8 (7 + 1 spare) dual polarized signals. These signals are processed by 8 independent spectrometer units working in parallel. A block diagram of the spectrometer is shown in Fig. 1. The 8 spectrometer units are connected to the Converter Racks (CR) outputs, which is the last stage of the GBT's intermediate frequency (IF) system. The spectrometer can broadly be divided into two parts: (1) FPGA based hardware and (2) pipeline computing facility. CASPER's ROACH² board is used as the FPGA based hardware. The pipeline computing will be implemented using a cluster computing facility (HPC).

The analog signals from the CR, after amplification and band limiting to 1.5 GHz, are fed to 8-bit ADCs attached to the ROACH boards. The sampling clock for the ADC is generated using a synthesizer, which is locked to the observatory 10 MHz standard. The FPGAs in the ROACH board process the digitized signal and send spectra and cross correlations of the two polarizations to the HPC through a 10 GbE switch. The HPC consists of 8 (+ 1 spare) independent PCs. Each PC will have a dual port 10 GbE card and a GPU GTX480 card. The GPU will be used for implementing observing modes with bandwidth ≤ 250 MHz and the 8 sub-band capability (see Section 3). One of the ports of the 10GbE card will receive data from the ROACH boards and the second port will send data to the data storage system. The HPC is connected to the data storage system through the same 10 GbE switch to which the ROACH boards are connected. The data storage system will be a parallel file system (eg. lustre) based storage and will support ~ 100 TB of disk space. For all the specified observing modes data will be written to this storage system. The GBT users will be accessing data from this storage system through a 1 GbE link as shown in Fig 1.

²see http://casper.berkeley.edu/wiki/ROACH



Figure 2: Software architecture of the GBT spectrometer

The monitor and control (M&C) of the whole spectrometer is done through a dedicated computer. The M&C system will obtain data from the ROACH board through a 1 GbE (or 100 MbE) network. A 10 GbE link to this network provides the M&C information from the HPC.

A 1 PPS signal from the observatory time standard is connected to the ROACH boards. This 1 PPS is the main synchronization signal for the spectrometer. Switching signals are used during observations to synchronize spectral measurements with noise and/or frequency switching. The internal switching signals are generated by one of the ROACH boards (Switching Master) and will be sent to other ROACH boards through a distribution system. The Switching Master will also accepts external switching signals and will send them to other boards through the same distribution system.

The spectrometer software architecture is shown in Fig. 2. The software components can be broadly divided into two parts – the M&C and the observing pipeline. The M&C is designed based on the existing GBT software system. In this system each hardware device is controlled by a 'manager'. The manager also sends the monitoring information at regular intervals. They also have the functionality to record data to a FITS file. In the spectrometer design, the ROACH M&C managers control the ROACH boards and the HPC M&C managers control the data acquisition and flow in the HPC units. The spectra from the ROACH are averaged to the required integration time and put in a shared memory by the data acquisition module. The HPC M&C manager reads the data from the shared memory and records to the disk storage system.

For FPA observations, the HPC M&C manager sends data to the data processing pipeline. This pipeline will produce a uniformly gridded, calibrated spectral map of the observing region as its end product. The operations of this pipeline can be divided into beam based calibration and mapping process. The beam based calibration process (GBT calibration pipeline) will be implemented in the HPC. After calibration, the HPC sends the data to a computer (Arcturus) where the spectral image is made by the mapping process.

3 Observing Modes

The spectrometer supports a variety of observing modes. The major modes of operation are single and 8 sub-band modes. In single sub-band mode the maximum bandwidth a spectrometer unit can process is 1.25 GHz. There will be 1024 spectral channels across this bandwidth which gives a spectral resolution of



Figure 3: (a) An example of the spectrometer configuration for single beam, dual polarized observations. The 8 spectrometer units can be tuned to different frequencies covering a bandwidth of up to 10 GHz. Each unit processes signals from two polarizations. (b)An example of the spectrometer mode for focal plane array observations. Each spectrometer unit processes a bandwidth of 1.25 GHz centered at the same observing frequency. In this example, there are 8 sub-bands, each of 15 MHz bandwidth, tuned to different frequencies within the 1.25 GHz bandwidth.

 ~ 1.5 KHz. The minimum integration time supported by this mode is 0.5 msec. The minimum bandwidth provided in single sub-band mode is 1 MHz with spectral resolution of 30 Hz (ie 32768 channels). The minimum integration time for this mode is about 10 msec. The spectrometer will support 8 fully tunable sub-bands within the 1.25 GHz bandwidth (see Fig. 3b). The center frequency of the sub-band is tunable to an accuracy of 10 KHz. The sub-band bandwidth varies from 30 MHz to 1 MHz. The number of spectral channels per sub-band for these different bandwidths is 4096.

The 8 spectrometer units can be configured in different observing modes. They can also be used together to process a contiguous bandwidth of up to 10 GHz. An example of using the spectrometer in this configuration is shown in Fig. 3a. The total number of sub-bands available when all the 8 units are used together is 64. For FPA observations, all the 8 spectrometer units will usually be configured to the same observing mode (see Fig. 3b).

Acknowledgments 4

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5 References

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