A Spectrometer for a GBT Focal Plane Array as part of a Family of Advanced Digital Backends

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Summary

We propose to build a 10-pixel spectrometer to match the proposed K-band focal plane array. Such a device would require $375k for M&S costs, and $577.5k for staff costs. Work would commence in fall 2007 and have a two year development time.

1. Introduction

The next generation focal plane array (FPA) receivers for the GBT will require orders of magnitude greater backend capacity than can be provided by the current GBT Spectrometer. The current GBT Spectrometer was expensive, required many years to design, construct and commission, and has considerable ongoing maintenance costs. Clearly, a new approach is needed. Although a single polarization of 8 pixels of a focal plane array could be used with the existing Spectrometer, this would dramatically curtail full use of such an array.

This proposal is to fund the hardware and staff effort costs to build a Spectrometer capable of supporting a 10 pixel FPA, while at the same time developing the expertise necessary to deliver a "family" of next generation advanced digital backends based upon this technology. This expertise will return NRAO to the forefront of current digital signal processing techniques, vital for a wide variety of future applications. It will also be directly relevant to our future participation in SKA technology development.

The Spectrometer would be built in collaboration between Green Bank and CDL, and would include a number of University partnerships.

2. Science Case

The new Spectrometer is a required component of any future focal plane array. The device proposed here is appropriate for the proposed K-band (18-26 GHz) 10-pixel array. Somewhat different specifications would be required (in particular wider instantaneous bandwidth for the individual IF channels) to support a W-band (68-92 GHz) array, although the same basic approach would be used were W-band chosen as the initial frequency. The science case for focal plane spectroscopic arrays at K- and W-band is described in the accompanying documents.

3. Current Development

For the last few months NRAO, in collaboration with West Virginia University and University of Cincinnati, has been prototyping an advanced digital backend using techniques developed at the Center for Astronomical Signal Processing and Electronics Research (CASPER) under the leadership of Dan Werthimer at UC Berkeley. The goal of CASPER is to streamline and reduce the current radio astronomy instrumentation design flow through the development of an open-source, platform-independent design approach. By incorporating reconfigurable, easily upgradeable hardware modules along with standard, GUI-based, parameterized design libraries (blocks), CASPER's approach succeeds in abstracting away most of the underlying details of instrument design and development. The overall process then simplifies to:

1) Representing a design through the creation of a high-level block diagram
2) Refining the design through simulation
3) Downloading the design into the target hardware for final testing, evaluation, deployment, and commissioning

Examples of devices developed using CASPER technology include the Arecibo Signal Processor (ASP), the Galactic Arecibo L-band Feed Array (GALFA) Spectrometer and the JPL SETI Spectrometer.

The promise of CASPER is to allow rapid development of new backends on timescales of six months to one or two years. Backends can be expanded simply by adding more modules, or taking advantage of more powerful hardware as it becomes available. Once a system has been delivered with basic functionality, the same hardware can be readily reprogrammed to provide successively more advanced capabilities.

The current project underway in Green Bank seeks to build an advanced pulsar backend, which ultimately will deliver the specifications previously described as "Scott's Dream Machine", specifically:

- Very wide (~1 GHz) bandwidth. A point of reference is ~600 MHz of usable bandwidth between 1650 and 2250 MHz.
- Wide dynamic range through 8-bit sampling.
- Full Stokes capability.
- Some built-in RFI excision capability (i.e. transient wideband and narrowband RFI removal. Our bandwidths are currently limited by very strong narrowband RFI).
- Ability to provide filter bank-style output.
- Ability to output coherently de-dispersed sub-bands.

Using the expertise gained in developing the above system, we will be ideally placed to develop a new spectrometer, which would share many of the same basic building blocks as the above system.

3. The Spectrometer

The specifications would be geared to match the capabilities of the prototype K-band array. Currently available sampler technology will provide ~ 1GHz bandwidth per IF channel, which could be placed anywhere within the 18-26 GHz bandwidth of the frontend. Future improvements in sampler technology would allow increased bandwidth per IF. The specification is thus for:

- 20 IF's
- 800 MHz - 1 GHz instantaneous bandwidth with 32000 channels per IF (not necessarily uniform distribution of channels, could be subbanded)
- 800 MHz-1600 MHz IF (or 1-2 if we have 1 GHz bandwidth)
- 32 bit integer results
- 10 ms maximum dump rate (200 MB/sec/bin, max 4 bins)

All processing would be done in the receiver room, thus avoiding any need to transfer signals (analog or digital) over optical fiber.

The current hardware costs for such a system would be as follows (next generation devices are actually likely to be cheaper):

Qty	Each	Description	Total
20	3K	iADC2 sampler	60K
10	7K	iBOB2 preprocessor	70K
5	35K	BEE3 FPGA Processor	175K
40	0.5K	Communication links	20K
1	25K	Backend computer/server	25K
1	25K	Packaging, etc	25K
Total			**375K**

Table 1: 20 Channel Spectrometer Hardware Costs

(Note: the above assumes no free Xilinx chips, which would save about $80K if it happens.)

Staff effort would be as follows, spread over two years.

Item	Effort (FTE years)
Project Management	0.25
Specifications and documentation	0.25
Engineering	1.0
Construction and documentation	1.25
Control Software	1.0
Data pipeline development	1.0
Commissioning	0.5
Total:	5.25
Cost:	$77.5K

Table 2: Staff Costs assuming average S+B of $110k

We anticipate that approximately 50% of Randy McCullough, 25% of Rich Lacasse and 25% of Jason Ray will become available later in CY2007 or early in CY2008 as their current projects come to fruition. Thus we anticipate that the science and electronics effort required can be supplied by existing staff, or via continued collaborations.

The above staffing costs do **not** include the cost of a full data reduction pipeline required to effectively utilize a multi-pixel array and backend. We anticipate that the majority of such a pipeline would be adapted from an existing system. Specifically, the University of Calgary Radio Astronomy Lab (UCRAL) is developing both data acquisition and data pipeline processing software to create spectral data cube images for the ALFA survey. UCRAL would be keen to collaborate with NRAO to adapt this software to the K-band array, and make it available for general use. The two fte-years of software effort is the NRAO effort necessary to participate in developing the pipeline for this Spectrometer. All staff in the GB Software Division are completely committed to existing projects for the foreseeable future. Thus this effort would have to come from a new hire.