Future GBT Instrumentation and Projects

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This docummment is an outcome of the Green Bank Telescope Future Instrumentation Workshop and subsequent discussions http://www.nrao.edu/GBT/fi/index.shtml. It has been assembled to guide our development program – it is a working document and not a final report. The order of the items does not reflect our priorities but goes, roughly speaking, from front ends to back ends, and from simple to complex. As items from this list are evaluated and turn from wishes into projects, information will appear on the GBT Project Development page: https://wikio.nrao.edu/bin/view/GBT/WebHome

Other references relevent to GBT instrumentation development include:

An overview of current GBT development plans is given in our section of the Program Plan: http://wiki.gb.nrao.edu/bin/view/Projects/WebHome Look for the entry *GBProgPlan2007V2.pdf* on this wiki page.

Rick Fisher's memo from October 2006 with comments on many of the projects and an expanded discussion of some of the technical issues: http://www.gb.nrao.edu/~jlockman/JRFsummary.txt.

Amy Shelton's document on software development issues arising from the Workshop:
http://www.gb.nrao.edu/~jlockman/FIW-Software.pdf.

Papers from a 2003 workshop on high frequency science with the GBT:
http://www.gb.nrao.edu/~bmason/gb-workshop-sep03/talks/index.html

1 Front Ends – Single Pixel Receivers

1.1 Improved receivers

Lower Tsys, better spectral baselines, improved RFI filtering This will benefit all projects and is not necessarily very expensive. Could be viewed as ongoing, but does require resources and effort. Increasing the bandwidth of receivers where possible is important, e.g., make all four K-band systems cover 18-26 GHz. Aim to match EVLA bands if possible. Continue work on highly integrated receivers like the C band system. Possibly piggyback on EVLA OMT design or develop electromagnetic 4-probe polarizer.

1.2 Extend frequency coverage

Frequencies < 50 GHz not now covered at the GBT

Frequency (GHz)	Notes
< 0.29	recomb. lines
2.60 – 3.95	CH, pulsars
5.85 – 8.00	methanol maser, OH maser
10.1 – 12.0	HC_7N, HC_5N
15.4 – 18.0	HC_7N, HC_5N, chemistry

1.3 First Generation W band receivers

This will open up the very rich 68-90 and 90-116 GHz bands. It would be used for chemical tracers of star formation, CO studies of molecular clouds (Galactic and extragalactic), redshifted molecular lines, chemistry, and VLBI. The existing plans call for a correlation receiver in the 68-90 band which could be used with the Caltech Continuum Backend and the Zpectrometer. This would be a "first science" instrument for PTCS improvements.

The 3mm project is described at http://www.gb.nrao.edu/electronics/projects/3mmRx/. An updated science case for the 68-90 GHz receiver is at: http://www.gb.nrao.edu/~dpisano/science_wband.pdf.

1.4 1.0 - 2.5 GHz wide-band receiver

Approximate frequency range for pulsar timing, eliminates the need to switch between receivers to get desired frequency coverage. Near-simultaneous observations over as wide a band as possible in the 1-2 GHz range is desirable. See Ransom's notes: http://www.gb.nrao.edu/~jlockman/pulsar_multiband.pdf.

1.5 Tertiary reflector for rapid position switching

Elimination of atmospheric effects, better baselines. Could be used with receivers at > 18 GHz, possibly lower frequency depending on design. Probably need one for each receiver band.

1.6 Feed rotator for polarization measurements and arrays

Needed for parallactic tracking – required for arrays.

2 Front Ends – Focal Plane Arrays

Focal Plane array development is a top priority identified by the Observatory Technical Council, see http://www.tuc.nrao.edu/~demerson/otc.html under the *Five-year Proposal (2007-2011)* section. A heterodyne focal plane array might easily exceed the capacity of our existing spectrometers and require not only a new spectrometer, but many other developments.

K Band (18-26 GHz) Mapping of molecular clouds and star-forming regions in molecules like NH_3 and CCS. The GBT focal plane can accommodate many tens of feeds covering 18-26 GHz with maximum loss of gain no greater than 1%. For conventional dual-polarization feeds the beam spacing on the sky would be ~ 3 HPBW. A 10-feed system would be a good prototype and a significant scientific instrument in its own right. Very complementary to the EVLA capabilities and a pathfinder instrument for the SKA. The science case for this instrument is at http://www.gb.nrao.edu/~jlockman/K_band_array.pdf. See also the presentation by J. Di Francesco at the GBT Workshop http://www.gb.nrao.edu/~jlockman/DiFrancesco_Kband.pdf.

Q Band (40-50 GHz) Many spectral lines in this band, but the science case is not thought to be as strong as for an array at K band at this time.

W Band (68-90 and 90-116 GHz) This will be a major facility of the GBT, providing wide-area coverage at good angular resolution, and very high surface brightness sensitivity. It will be very complementary to the capabilities of ALMA. At the current time this is quite a leap as we have no experience with focal plane array technology and the telescope does not yet work well at these frequencies, but a W band array is a goal. A discussion of the science this would enable is given in https://wikio.nrao.edu/bin/view/GBT/GbtFocalPlaneArrays

Ka Band (26-40 GHz) Continuum mapping for cosmology. OCRA 100-beam project at Jodrell has developed a prototype, and there is strong interest from CalTech. Would be a good instrument for collaborative development.

Ku Band (12.0-15.4 GHz) Good band for chemistry of heavy molecules. Matches the angular resolution of all-sky surveys done with the VLA.

2.1 Next Generation Bolometer Array

Potential for significant science in S-Z work, star formation, high-z galaxies. A straightforward expansion of the current 8x8 Penn array to 8x32 seems relatively inexpensive. Need demonstration of science with the Penn Array before taking the next step. A precis of the science case for bolometer arrays on the GBT is at http://www.gb.nrao.edu/~jlockman/bolometerScienceShortMar07.pdf. "Science with Bolometer Arrays on the GBT" by Brian Mason reviews the science drivers for both the Penn Array which is now being installed on the GBT, and a possible 6400 pixel 3mm bolometer array: http://www.gb.nrao.edu/~bmason/gbt-dev/gbt-cont-science.ps.

3 Front Ends – Beam Forming (phased) arrays

These are under development at many places around the world, but as yet no one has produced a working device for radio astronomy. These devices will be the required technology for any multi-pixel receivers on the GBT at frequencies below a few GHz, and would be superior to conventional feed-horn focal plane arrays at all frequencies, provided that their sensitivity is acceptable. More of a research than development area at this time. Good possibilities for collaboration with CDL, DRAO, ATNF, BYU? These devices have a strong software component and strong connection to SKA. The scientific case is described in a document from 2001: http://www.gb.nrao.edu/~jlockman/GBT-bfa-report.pdf.

4 Front Ends – Dual band receivers

Some experiments benefit from the capability of observing at two receiver bands simultaneously. Some thoughts on this topic can be found at http://www.gb.nrao.edu/~jlockman/GBT-dualbandv2.txt

K/Q With a dichroic and tertiary reflector, this would be a cheap way of getting simultaneous coverage of both bands if losses are not too large. Useful for molecular spectroscopy, astrochemistry, some continuum studies.

S/X The VLB dual-frequency bands. Demand for this on the GBT seems low.

0.8/2 GHz The current favorite frequency pairing for pulsar timing experiments. Possibly build a system entirely at prime focus? Parkes has a dual 0.64-0.7/2.6-3.6 GHz system with Tsys=40/30 K.

5 Advanced Digital Backend Development

New FPGA and Graphical Processing Unit (GPU) technologies promise breakthroughs in backend development. Good potential for collaboration with CDL, university groups, and other observatories. Anything we do in this area will be applicable to the SKA.

5.1 New Pulsar Backend

Increased capabilities for pulsar research – our first "public" general purpose pulsar backend. Could open up pulsar studies to more diverse groups of researchers. See the description by Scott Ransom at http://www.gb.nrao.edu/~jlockman/new_pulsar_instrument.txt. Some development is already underway using FPGA technology; possible inclusion of GPU technology. Active collaboration with WVU, Univ. Cincinatti, Berkeley. The science case is given in the Workshop presentation by Don Backer: http://www.gb.nrao.edu/~jlockman/Backer_timing.pdf A discussion of specifications and technical issues is in the Workshop presentation by Bryan Jacoby:
http://www.gb.nrao.edu/~jlockman/Jacoby_pulsarbackends.pdf.

5.2 New Spectrometer

The existing spectrometer is already inadequate – we need more IFs and channels. Any array receiver will require a new spectrometer, as will dual-band receivers. A new spectrometer might take advantage of new FPGA and GPU technologies and be developed and built relative quickly. Specifications need to be worked out in detail.

5.3 Cluster Computing

New technologies should be explored to provide the improved data processing capabilities we will need for the next generation of GBT instrumentation: pulsar backends, focal plane arrays, and advanced spectrometers.

6 RFI Excision

We must do more in this area. Perhaps focus our initial efforts on blanking the Bedford Radar? Excision should be considered in the design of every new front and back end. Strong connection to SKA. Need to explore techniques:

Blanking

High time resolution observing

High dynamic range systems

Signal processing algorithm development

7 Telescope Improvements – PTCS

This are critical for expanding the performance of the GBT and the number of hours available for high-frequency observing. The atmosphere permits several thousand hours of mm-observing per year, but we currently can use only about 10% of all clear-weather hours because of restrictions to calm nights, etc. Improvements will, for example, allow Q-band observing of the Galactic center during winter days. Work in conjunction with Penn Array and first-generation W band heterodyne receiver will open up major new research areas. Improvements will be made to the aperture efficiency, pointing, and tracking: http://wiki.gb.nrao.edu/bin/view/PTCS/WebHome.

8 Data Reduction

Need the next generation of software, also hardware like cluster computing. Need to explore possibilities for parallel processing. Need better flagging and editing, RFI excision tools. Provide pulsar reduction software for the first time in NRAO history? Development of techniques for wide-band observing, mapping. Archive issues connected to e2e project. Applicable to the SKA.

9 Networking improvements

Necessary for archiving, export of data.