

# Advanced Multi-beam Spectrometer for the GBT: Specifications

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## Overview of the talk

- Science and calibration requirements
- Specifications
- Considerations for further development in the near future

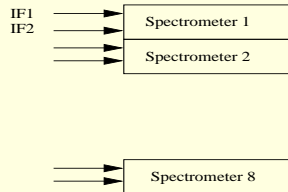
# 1. General Considerations

- Primarily a spectral line system
  - Full polarization spectral line observations with single beam
  - Full polarization spectral line imaging with focal plane array
- General pulsar observing modes **will not** be supported in the project time scale
- Cross correlation between feeds for a focal plane array **will not** be supported

## 2. Science Considerations – KFPA

- KFPA available now, which has 7 beams
- **Specification:** need to process 7 + 1 spare beam; 8 dual polarized signals; Full Stokes measurement
- **Specification:** Design should be scalable for observing with larger array in the near future

A simple spectrometer configuration



(spec per spectrometer)

### 3. Science considerations: 1 Sub-band Obs Modes

- **Maximum Bandwidth :**

Extragalactic observations  $\leq 3000 \text{ km s}^{-1}$

$\Rightarrow 900 \text{ MHz}$  at  $90 \text{ GHz}$ .

Converter Rack lower cutoff freq  $150 \text{ MHz}$ ;

$1050 \text{ MHz}$  (min) digitized bandwidth to avoid further mixing etc

- **Velocity resolution and velocity range**

- Maser  $\sim 100 \text{ km s}^{-1}$  and  $\Delta V \sim 0.01 \text{ km s}^{-1}$

- $\Rightarrow 555 \text{ KHz}$  ( $1 \text{ MHz}$  for dual Dicke) and  $55 \text{ Hz}$  at  $1665 \text{ MHz}$

- Extragalactic CO obs:  $\sim 3000 \text{ km s}^{-1}$  and  $\Delta V \sim 5 \text{ km s}^{-1}$

- $\Rightarrow 900 \text{ MHz}$  and  $1.5 \text{ MHz}$  near  $80$  to  $90 \text{ GHz}$

- $22 \text{ GHz H}_2\text{O}$  maser:  $5000 \text{ km s}^{-1}$  and  $0.3 \text{ km s}^{-1}$

- $\Rightarrow 370 \text{ MHz}$  and  $22 \text{ KHz}$  at  $22 \text{ GHz}$

## 4. Specifications: 1 Sub-band Obs Modes

| Number of sub-bands per IF | Sub-band Bandwidth <sup>b</sup><br>(MHz) | Number of channels per sub-band per IF | Spectral resolution<br>(KHz) | Integration time  |                  | Priority |
|----------------------------|--|--|------------------------------|-------------------|------------------|----------|
|                            |  |  |                              | minimum<br>(msec) | maximum<br>(sec) |          |
| 1                          | 1500                                     | 1024                                   | 1465                         | 0.5               | 60               | 1        |
| 1                          | 1000                                     | 2048                                   | 488                          | 0.7               | 60               |          |
| 1                          | 800                                      | 4096                                   | 195                          | 1.3               | 60               |          |
| 1                          | 500                                      | 8192                                   | 61                           | 2.5               | 60               |          |
| 1                          | 400                                      | 16384                                  | 24                           | 5                 | 60               |          |
| 1                          | 250                                      | 32768                                  | 7.6                          | 10                | 60               |          |
| 1                          | 100                                      | 32768                                  | 3.1                          | 10                | 60               |          |
| 1                          | 50                                       | 32768                                  | 1.5                          | 10                | 60               |          |
| 1                          | 25                                       | 32768                                  | 0.8                          | 10                | 60               |          |
| 1                          | 10                                       | 32768                                  | 0.3                          | 10                | 60               | 3        |
| 1                          | 5  | 32768                                  | 0.15                         | 10                | 60               |          |
| 1                          | 1  | 32768                                  | 0.03                         | 10                | 60               | 4        |

## 5. Science considerations: Multiple Sub-band Obs Modes

Number of Sub-bands, sub-band bandwidth and resolution :

- $\text{NH}_3$  at 22 GHz: about 8 lines within 900 MHz BW;  
Sub-band bandwidth: needed  $\sim 100 \text{ km s}^{-1} \times 2$  for dual Dicke  $\Rightarrow 14 \text{ MHz}$ .  
Spectral resolution:  $\sim 0.04 \text{ km s}^{-1} \Rightarrow 3 \text{ KHz}$ ; 4700 channels
- RRL : 20 to 30 transitions at low freq bands ( $< 1.4 \text{ GHz}$ ).  
Sub-band bandwidth: need  $\sim 500 \text{ km s}^{-1} \times 2$  for dual Dicke  $\Rightarrow 1 \text{ MHz}$  at 340 MHz  
Spectral resolution:  $\sim 1 \text{ km s}^{-1} \Rightarrow 1 \text{ KHz}$ ; 100 channels
- Extragal RRL

## 6. Specifications : Multiple Sub-band Obs Modes

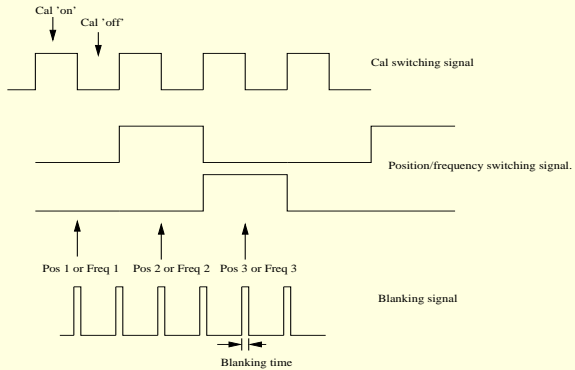
| Number of sub-bands per IF | Sub-band Bandwidth <sup>b</sup><br>(MHz) | Number of channels per sub-band per IF | Spectral resolution<br>(KHz) | Integration time  |                  | Priority |
|----------------------------|--|--|------------------------------|-------------------|------------------|----------|
|                            |  |  |                              | minimum<br>(msec) | maximum<br>(sec) |          |
| 8                          | 30                                       | 4096                                   | 7.3                          | 10                | 60               | 2        |
| 8                          | 15                                       | 4096                                   | 3.7                          | 10                | 60               |          |
| 8                          | 10                                       | 4096                                   | 2.4                          | 10                | 60               |          |
| 8                          | 5  | 4096                                   | 1.2                          | 10                | 60               |          |
| 8                          | 1  | 4096                                   | 0.2                          | 10                | 60               |          |

**Tunable any where within the digitized band with 10 KHz resolution.**

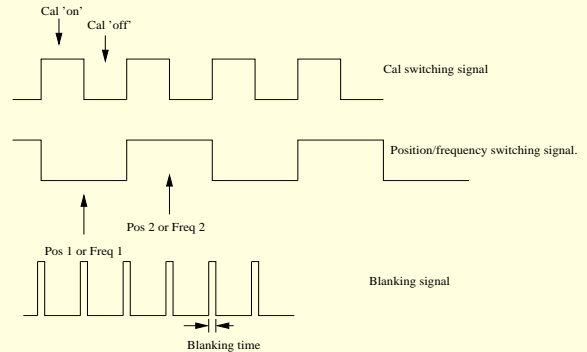


## 7. Calibration considerations: Switching signal

- Need cal, frequency, nodding, blanking signal
- 1 to 6 switching states
- KFPA mapping needs 100 msec integration per position.



Timing diagram for 6 switching states



Timing diagram for 4 switching states

## 8. Specifications: Switching signal

| Timing                              |  |               |               |               |
|-------------------------------------|--|---------------|---------------|---------------|
|                                     | 'on' time <sup>a</sup>   |               | Blanking time |               |
|                                     | min<br>(msec)  | max<br>(msec) | min<br>(msec) | max<br>(msec) |
| Cal sw sig. <sup>b</sup>            | 25   | 500           | 0.5           | 50            |
| Freq/Pos sw sig.                    | 50   | 1000          | 2             | 1000          |
| 'Look ahead' sig.<br>advance time   | min 0.1 sec; max 1 sec   |               |               |               |
| Number of switching states          | min 1; max 6   |               |               |               |
| Number of bits for Freq/Pos sw sig. | 2  |               |               |               |
| Number of bits for Cal sw sig.      | 1  |               |               |               |
| Source for sw sig.                  | Internally generated & External  |               |               |               |
| Data Packetization                  | Switching states need to be encoded<br>in the output data from the hardware. |               |               |               |
|                                     |  |               |               |               |

## 9. Science considerations: Data Dumping

- Galactic center pulsar search: 0.5 msec integration  
(1024 channels, 32 bit spec, 0.5 msec  $\Rightarrow$  15 MB/sec)

If pulsar detected; may need full stokes  $\Rightarrow$  30 MB/sec

- Stellar cyclotron maser instability obs: 10 msec  
(32 K, 32 bit spec, 10 msec, full Stokes  $\Rightarrow$  50 MB/sec)

**Specification:** Keeping near future development option

– 100 MB/sec per spectrometer

## 10. Technical considerations: Digitization

- RFI power –  $10^3$  to  $10^4$   $T_{\text{sys}} \Delta f$  (= 12 KHz)  
Spur level when observed with 1 KHz resolution and 12 hrs integration <  $-89$  dBc
- Difficult to achieve this in the project time scale;  
analog system may limit before the digitizer.
- Chosen the best available ADC card :  
8 bit, 1.5 GHz, dual channel, 52 dB (SFDR and IMD).
- Isolation between IF and ADC channels:  
**Spec:** > 60 dB (from Polarization obs requirement)  
**Degraded spec:** > 35 dB; coupled power changes only by 1% over 1 hr

## 11. Specifications: HPC and Data storage

- Up to 6 states of integrated spectra to be formed from the data sent by ROACH in the various specified modes.
- GBT pipeline implementation: beam based calibration, Doppler tracking of sub-bands, imaging using 8 beam data.
- Record raw data in SDFITs (minimum spec), record FITS images

## 12. Specifications: Summary

|  |  |
|--|--|
| Spectrometer output                      | self of IF1, self of IF2, cross of IF1 & IF2   |
| Spectral values                          | 32 bit quantized   |
| Digitized bandwidth for each IF          | $\geq 1050$ MHz  |
| Isolation between IFs<br>(degraded spec) | $\geq 60$ dB<br>$\geq 35$ dB<br>The coupled power should not vary by more than 1% in 1 hour                                      |
| Integration time in the hardware         | 0.5 msec to 2 sec  |
| SFDR & IMD                               | As specified by ADC 083000   |
| Spectral filter response                 | stop-band rejection $\geq 90$ dB;<br>stop-band is channels $> \pm 1.0$ resolution unit<br>$< 0.1$ dB ripple within 3dB bandwidth |
| Band reduction filter response           | $< 0.1$ dB ripple within 3dB bandwidth<br>Aliased power $< 20$ dB of in-band power<br>Roll-off: 20 dB in 1% of the bandwidth     |
| Direct Digital Converter LO              | $> 16$ bits, 10 KHz resolution   |
| <b>HPC, Data Storage and Monitoring</b>  |  |
| Data rate to disk                        | 100 MB/sec per beam (2 IFs), full Stokes   |
| Integration time in the HPC              | 2 sec to 1 minute  |
| Processing pipelines                     | KFPA mapping, single beam (2 IFs) observation,<br>fast spectral dump to disk (see text for details)                              |
| Data output format                       | FITS images for KFPA, SDFITS for other observations  |
| Monitoring                               | Optional display of the spectrum every 30 sec  |

### 13. Specifications: Analog system and Sampling clock

| <b>Specifications per analog unit</b>             |  |
|---|--|
| Anti-aliasing filter                              | Low pass filter with 3dB cutoff freq 1.5 GHz<br>stop-band rejection > 20 dB<br>Roll-off: 20 dB per 100 MHz<br>< 0.1 dB ripple within the 3dB bandwidth |
| Analog input power level                          | +2 dBm for full-scale of the 8 bit ADC<br>-40 dBm for 1 bit fluctuation  |
| Intermodulation ; output IP3                      | > 31 dBm   |
| <b>Specifications sampling clock distribution</b> |  |
| Clock freq  | 1.5 GHz  |
| Clock waveform                                    | sine wave  |
| Ref input freq                                    | 10 MHz   |
| Ref waveform                                      | sine wave  |
| Ref power   | 0 dBm  |
| Jitter at the ADC clock input port                | $\leq 0.61$ ps   |
| Jitter (degraded)                                 | $\leq 3.1$ ps  |
| Power at ADC clock input port                     | 0 dBm  |

## 14. Wide-band spectrometer for single beam obs

Combine the 8 spectrometers to process larger bandwidth.

- Total bandwidth – 1.25 to 10 GHz
- Total number of sub-bands –  $8 \times 8 = 64$
- Full pol obs; supporting all modes specified earlier.
- Different spectrometers need to operate in different modes.



## 15. Near future developments

- Data recording at 100 MB/sec
- HPC will have local disks and option for adding additional disk to increase data rate.
- Streaming one spectrometer output data to the remaining 7 to get higher data rate for any on-line processing or recording to local disk in HPC.
- GPU's in each HPC node for pulsar and RFI excision application.