GBT Spectrometer Spigot Card for Pulsar Observations

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- ## Introduction

The purpose of this paper is to give a description of one possible design of a pulsar spigot card for the GBT spectrometer. The ideal behind such a card would be to stream raw correlation results as fast as possible onto a recording medium for later analysis. Such a strategy will bypass the main data rate limiting elements of the GBT spectrometer (the LTA and the computer interface).

While NRAO is very familiar with the GBT interface of the spigot card being proposed, very little is known at present about the data storage unit interface. Hence, specific information on the output interface is not presented.

- ## Raw data rate

Every 1.31072 milliseconds, internally integrated auto-correlation results from the GBT 1024-lag correlator chips are dumped into long term integration (the LTA). Each of the 4 quadrants in the spectrometer has a blank logic card slot that bridges across the correlator card-LTA interface over which these results flow. One intention for this "spigot card" slot was the future possibility of designing a card such as the one described here that could provide faster access to short integrations than via the LTA.

Every 1.31072 msec, all 64 correlator chip in a given quadrant of the spectrometer will dump 1024 16-bit lag integrations into the LTA system. Thus the raw data rate into the spigot card is:

$$(64 \times 1024 \times 16) / (1.31072 \times 10^{**}\text{-}3) = 800 \text{ Mbits/sec} = 100 \text{ MBytes/sec}$$

(There is also a 1025th integration count result from each correlator chip that need not be preserved.)

In pulsar mode, the spectrometer can limit integration time in the individual chips to a value much shorter that the 1.3-msec system cycle time. In addition, the reduction in S/N incurred by processing fewer that the full number of bits produced in any given integration is sometimes acceptable. The table below shows the data rate produced by one quadrant of the spectrometer as a function of the number of bits of precision retained for each lag integration (the storage time listed in the table gives the time required to fill 100 GB of disc):

Number of bits per lag	Transmission rate	Storage time
16	100 MB/sec	100 seconds
4	25 MB/sec	67 minutes
3	18.75 MB/sec	90 minutes
2	12.5 MB/sec	2.2 hours
1	6.25 MB/sec	4.4 hours

Pulsar mode runs with the correlator chips in a quadrant being used to divide up the 1.3 msec system dump cycle into shorter intervals in order to produce integrations with high time resolution. The first table on the next page shows how many bits of precision the GBT correlator chips produce for typical short integrations. Also shown in the table is the number of significant bits that are contained within the raw correlator result from the relation:

RMS noise in integration ~ SQRT (number of samples in integration)

For an integration of 10.24 usec duration, for example, 1024 samples are processed when sampling at 100 MHz (50 MHz bandwidth) and 16384 samples are processed when sampling at 1.6 GHz (800 MHz BW). Thus, of the 10 bits resulting from a 10.24 usec integration for 100 MHz sampling, SQRT (1024) = 32 = 2**5 or 5 bits are noise. The VLA standard is that 5-3 or 2 bits may be discarded and hence the number of bits in the 10.24 usec integration (when sampling at 100 MHz) that must be retained in order to suffer little loss of S/N is 8.

Integration time	# bits per lag produced		# bits required to be kept	
	50 MHz	800 MHz	50 MHz	800 MHz
81.92 usec	13	17	9.5	11.5
40.96 usec	12	16	9	11
20.48 usec	11	15	8.5	10.5
10.24 usec	10	14	8	10
5.12 usec	9	13	7.5	9.5

- Modes

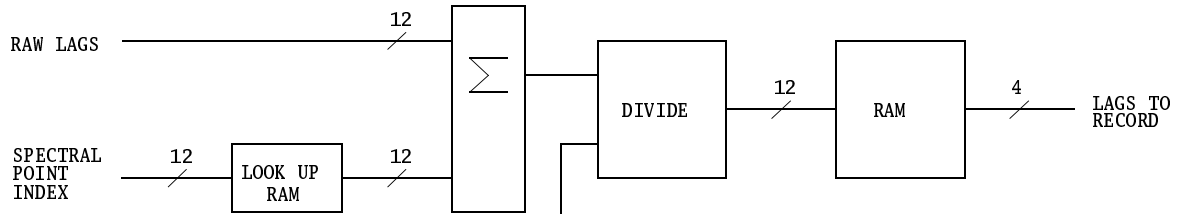The table below gives the modes available in one quadrant of the GBT spectrometer in pulsar mode.

Time resolution	Number of RF channels	Number of lags
81.92 usec	2	2048
40.96 usec	2	1024
20.48 usec	2	512
20.48 usec	2	256
40.96 usec	1	2048
20.48 usec	1	1024
10.24 usec	1	512
5.12 usec	1	256

If all 4 quadrants of the GBT spectrometer are fitted with streaming data storage systems such as is being proposed here, performance will increase by a factor of 4 from that shown above.

- Hardware

The spigot card being proposed will be reasonable simple (ignoring the data storage interface, for the moment). A single Xilinx FPGA should be more that enough to handle all necessary logic functions. A simple GBT standard Dallas Semiconductor 87C520 microprocessor is provided for interface to the GBT monitor and control system.

The FPGA will provide capture of raw correlator chip lags. A small look-up table RAM, programmed by the microprocessor, will remove DC components from the raw lags on a lag-by-lag basis (that is, each lag will have an independent DC offset correction parameter). Lags will then be normalized and then reduced to the number of bits to be retained and then sent to the record system for storage.

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RAW LAGS ─────────────── 12 ┌──────┐
                          /  │  ∑   │
                             │      │──── ┌────────┐  12  ┌──────┐  4   LAGS TO
                             │      │     │ DIVIDE │──/───│ RAM  │──/── RECORD
SPECTRAL    12  ┌────────┐ 12│      │     └────────┘      └──────┘
POINT      ─/──│LOOK UP │─/──│      │
INDEX          │  RAM   │    └──────┘
               └────────┘

NORMALIZATION
FACTOR
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   A Virtex XCV300 FPGA is tentatively selected to provide most of the logic required as described so far (because there is a small number of unneeded chips originally bought for the ALMA correlator available). This part may, however, not have enough internal RAM available for the required conversion look-up tables and, hence, some external RAM may be required.

Two small changes to the GBT spectrometer may be desirable to obtain the best performance from the pulsar spigot card. Adding 100 MHz clock and 1 second tick signals onto the spigot card input connector would allow more efficient use of the Xilinx FPGA chip since it will operate at a much higher clock rate that the 16.6 MHz output rate of the correlator card results. The one second tick will allow retention of precise observational timing.

It will be possible to double buffer all of the look-up table RAM contents so that corrections for system drift can be made during the progress of an observation. The monitor and control computer will have access to the same data being recorded at a lower rate through the normal LTA data path and could, in principal, generate corrected look-up tables as needed.

5) Cost estimate

Based of the ALMA experience, NRE of such a simple spigot card should be around $1,000 plus $250, each, for the card itself and about $500 for parts.