REAL-TIME BEAMFORMING FOR THE FOCAL L-BAND ARRAY ON THE GREEN BANK TELESCOPE (FLAG)

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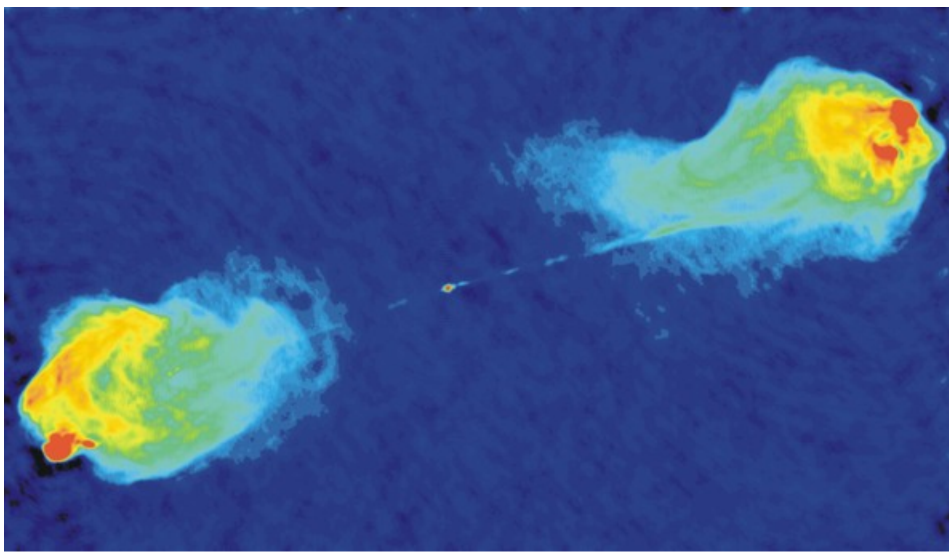
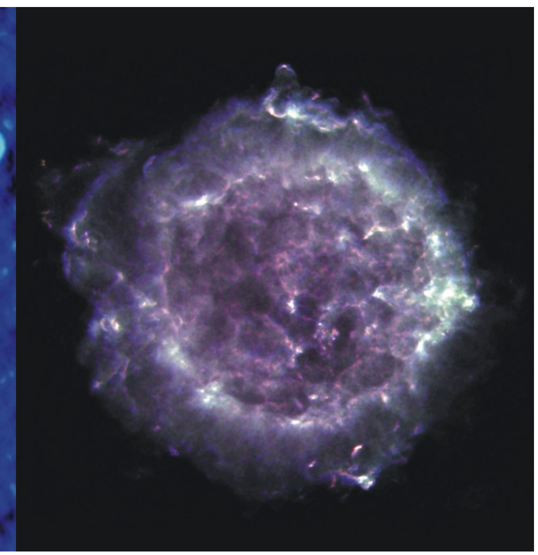
OUTLINE

- INTRODUCTION
- BACKGROUND
- FLAG SYSTEM OVERVIEW
- FLAG DIGITAL BACK END
- FLAG TESTING/COMMISSIONING
- CONCLUSION AND FUTURE WORK

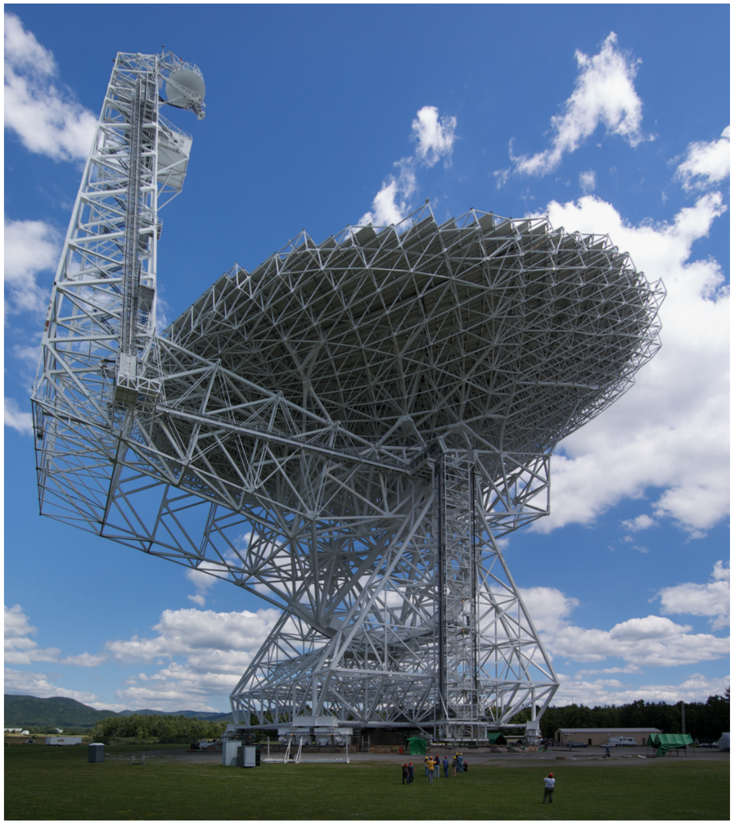
INTRODUCTION

- Radio astronomy – The study of radio sources in deep space.
- The signals received from the sources are 20 dB or more below the noise floor.
- Sources include pulsars, Fast Radio Bursts (FRBs), HI galaxies, etc.

GREEN BANK TELESCOPE (GBT)

- The world's largest fully steerable telescope (100 m diameter reflector).
- Located at the Green Bank Observatory (GBO) in West Virginia.
- Focal L-band Array for the Green Bank Telescope (FLAG) deployment.
- Instrument placed at the feed of the telescope.



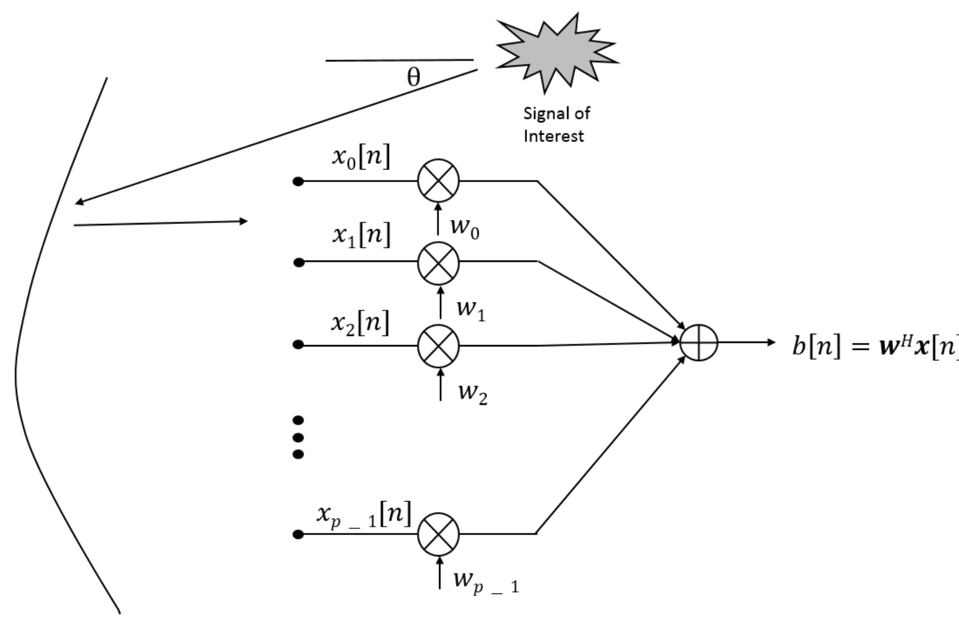
BACKGROUND

Phased Array Feeds (PAFs)

- A 2-D planar array of antennas placed at the focus of a large telescope dish that spatially samples the focal plane.
- Focuses a tight airy pattern spot of energy at the array.
- Advantages:
  - Larger field of view than the traditional single-pixel horn feed.
  - Increased survey speed due to large field of view.
  - Sensitivity optimization due to an increase in effective aperture area (A_e).
  - Radio frequency interference mitigation.
- FLAG used to detect sources such as HI galaxies, pulsars, and FRBs.
- Detect radio transient sources using real-time beamforming.

PAF BEAMFORMING

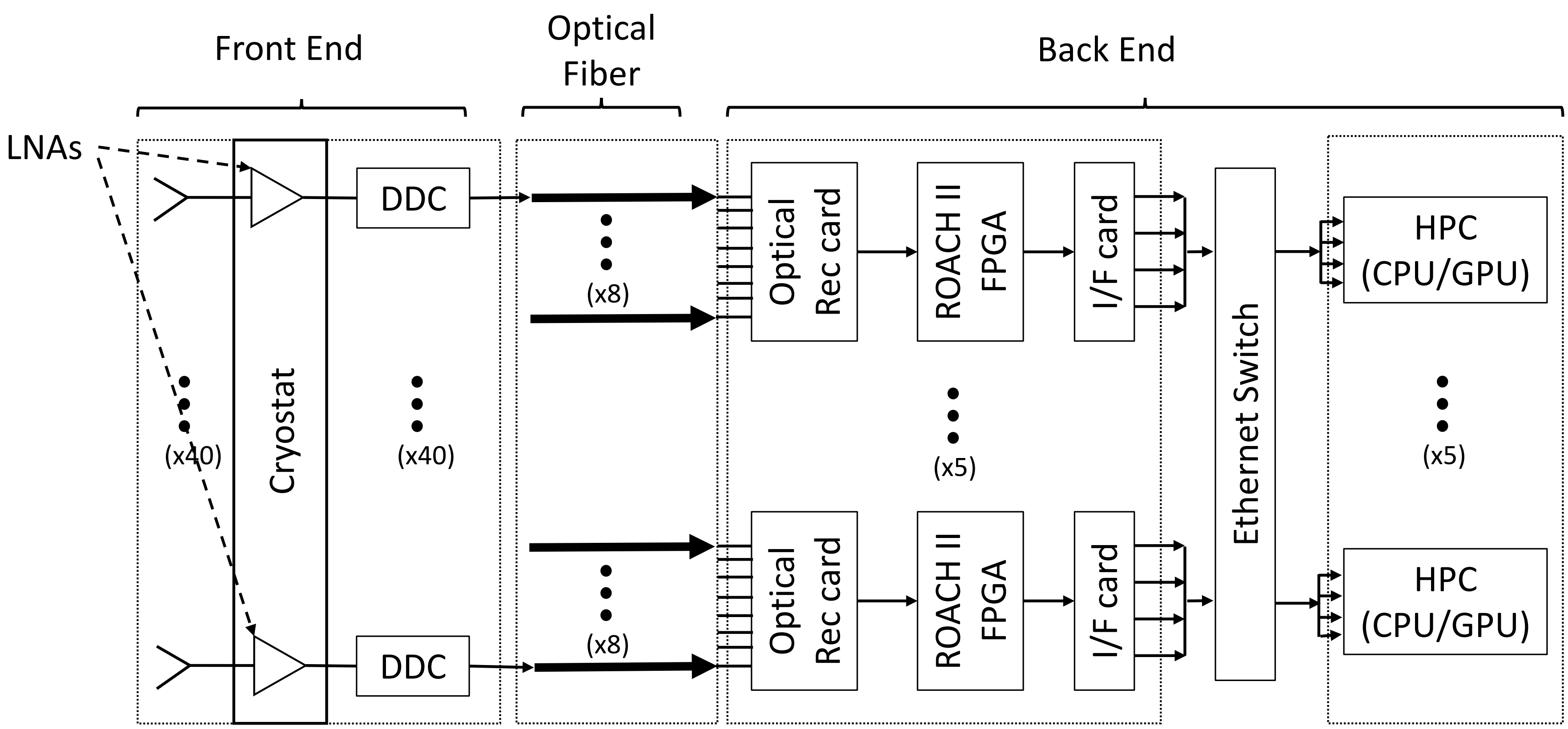
- PAFs used to form multiple simultaneous beams over a field of view referred to as beamforming.
- Sample voltages received by each element.
- Multiplied by complex weight coefficient.
- Summed across elements to form beam in direction, θ.



FOCAL L-BAND ARRAY FOR THE GBT (FLAG)

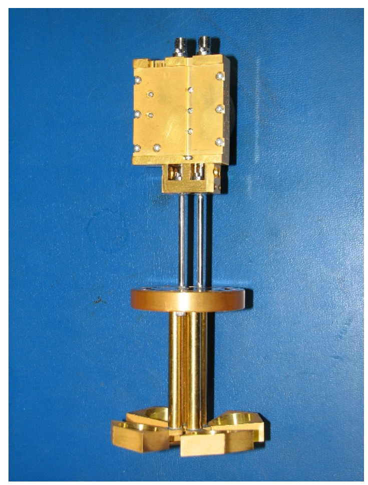
- Wide field astronomical PAF receiver with broadband signal processing and operational science observation capability.
- Back end currently in development by BYU, GBO, and WVU.
- Performs fine/coarse channel correlation as well as real-time beamforming.

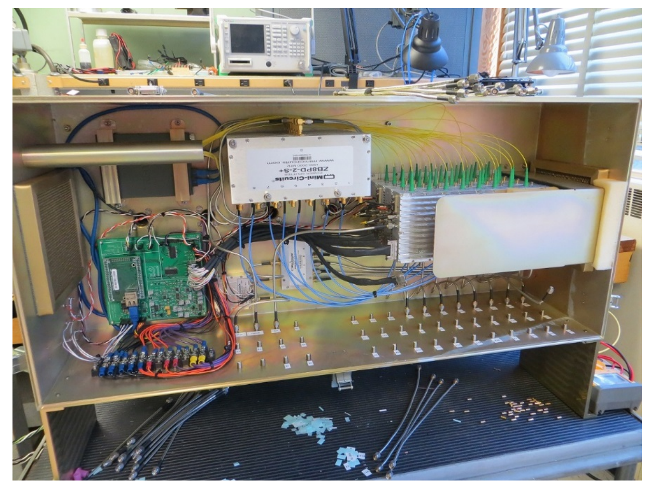
FLAG SYSTEM OVERVIEW



PAF RECEIVER FRONT END

- 19 dual-polarization element array built by Brigham Young University.
- Cryogenically cooled low noise amplifiers (LNAs) built at the National Radio Astronomy Observatory (NRAO).
- Digital down converter directly samples and digitizes the signal before it is transported over fiber.

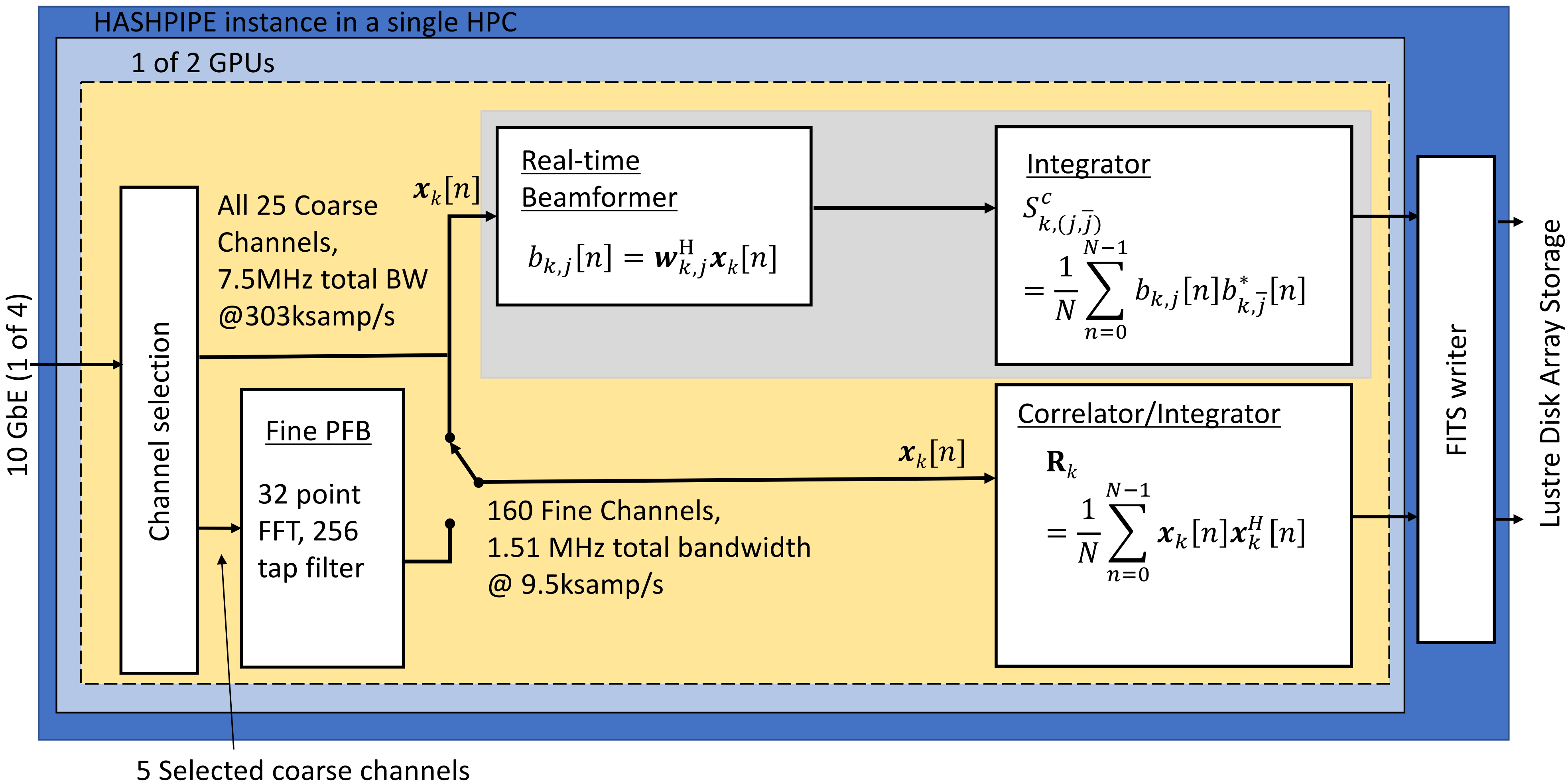




FLAG DIGITAL BACK END

- 5 digital optical receiver cards connected to 5 ROACH II FPGA boards which are in turn connected to 5 I/F cards.
- The ethernet switch packetizes the data further for the 5 High Performance Computers (HPCs).
- Each HPC contains 2 Graphical Processing Units (GPUs) for parallel computation.
- 150 MHz bandwidth (500 frequency bins) evenly distributed across HPCs.
- There are 100 frequency bins per HPC each 303 kHz wide.

HPC FUNCTIONAL BLOCK DIAGRAM

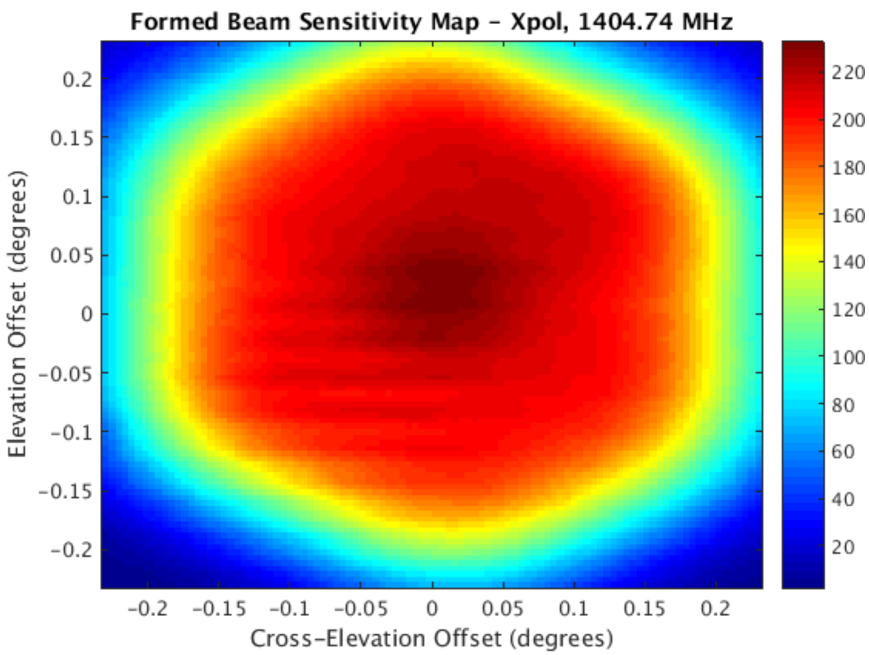


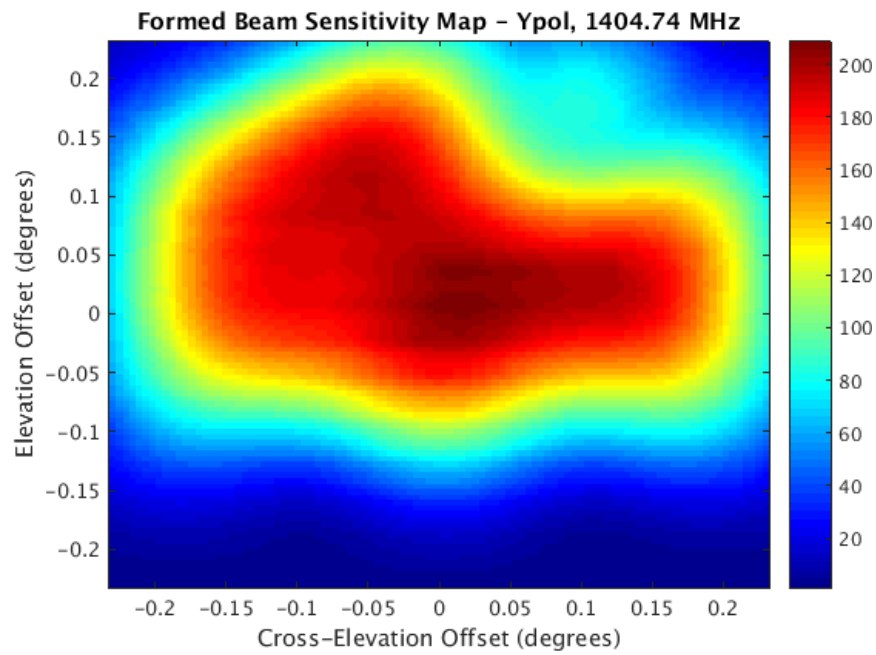
FLAG TESTING/COMMISSIONING

- Three commissioning runs.
  - July 2016
  - May 2017
  - July 2017
- Data was analyzed using:
  - T_{sys}/η which is the ratio of the system noise temperature to the antenna efficiency.
  - Sensitivity maps which indicate sensitivity ($A_p\eta/T_{sys}$) at different coordinates within the field of view.
  - Element patterns.
  - Beam patterns.
- T_{sys}/η of 28.2 K was recorded which is comparable to that of the single-pixel horn feed.
- Radio source plots were generated by PhD students from WVU.

SENSITIVITY MAPS

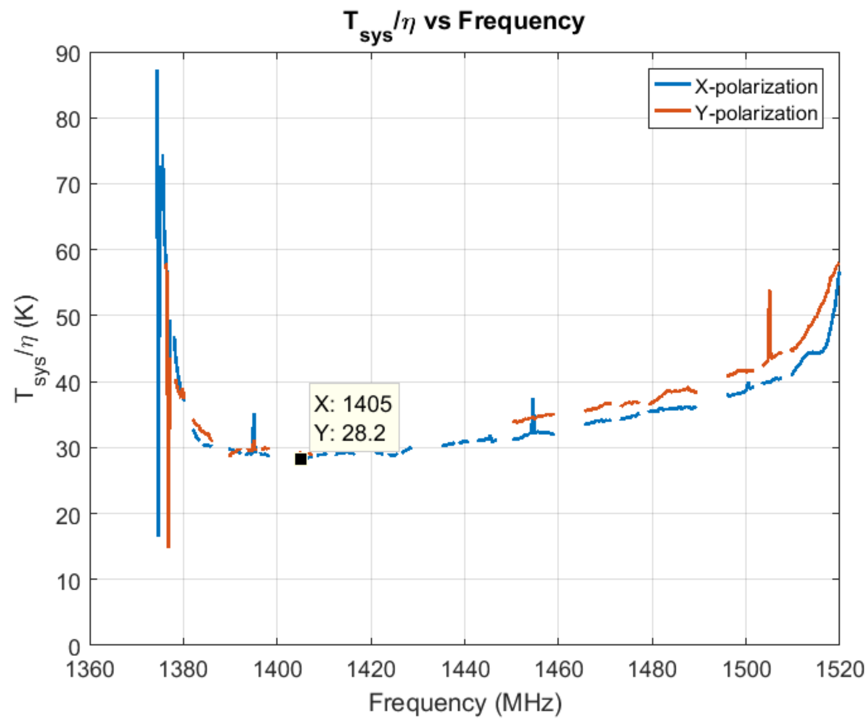
- X-polarization (left) and Y-polarization (right).
- Cross-elevation and elevation coordinates on the x and y axes respectively.





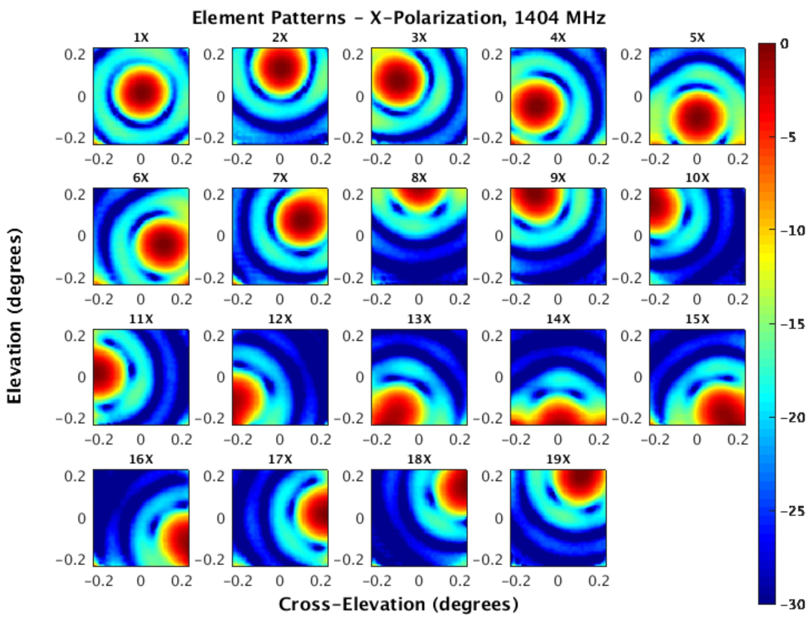
T_{sys}/η

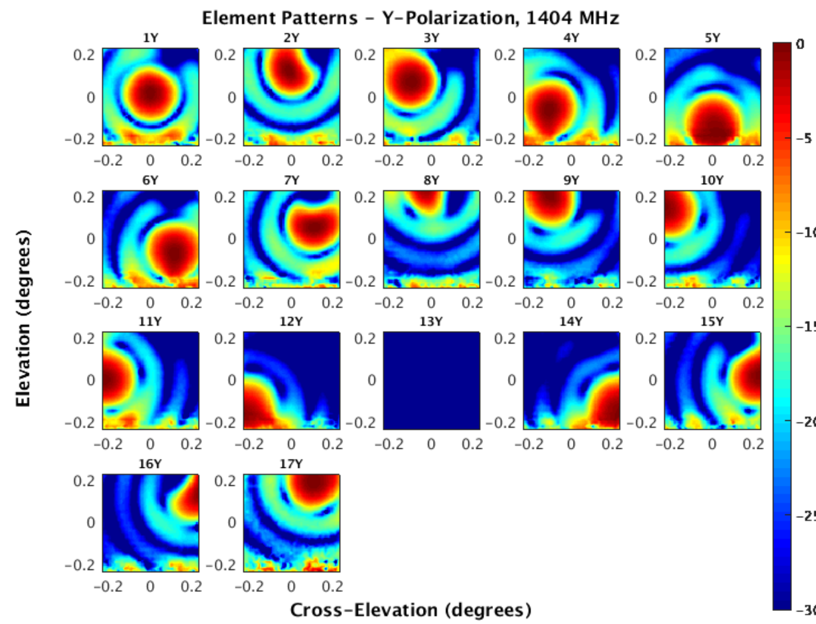
- X and Y polarizations are shown in the figure.
- The plot shows the measured T_{sys}/η of 28.2 K at approximately 1405 MHz.
- The gaps are masking the RFI in the plot and only 2 out of 5 of the bandwidth was available during this commissioning run.



ELEMENT PATTERNS

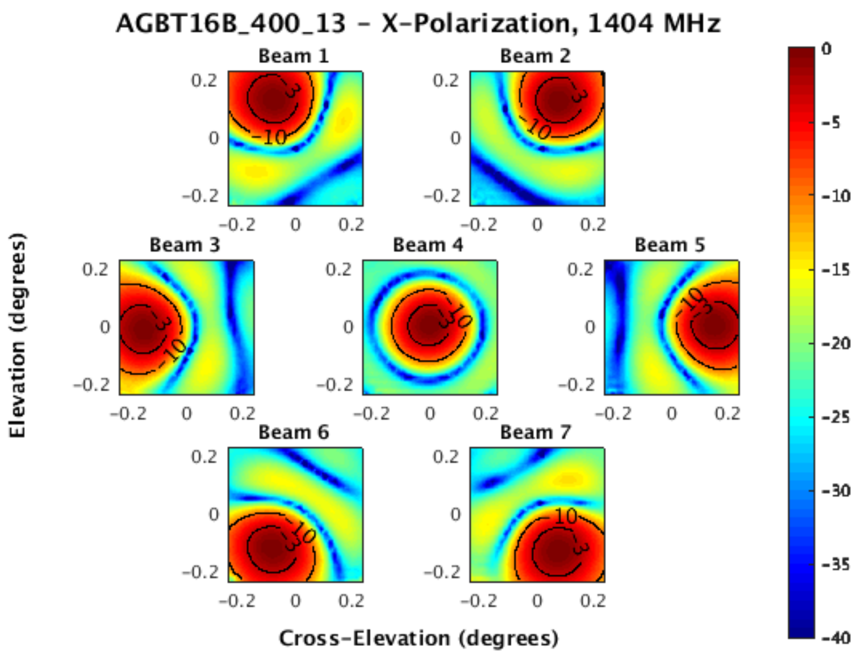
- X polarization (left) and Y polarization (right).
- Distortion in Y-polarization is due to malfunctioning elements.

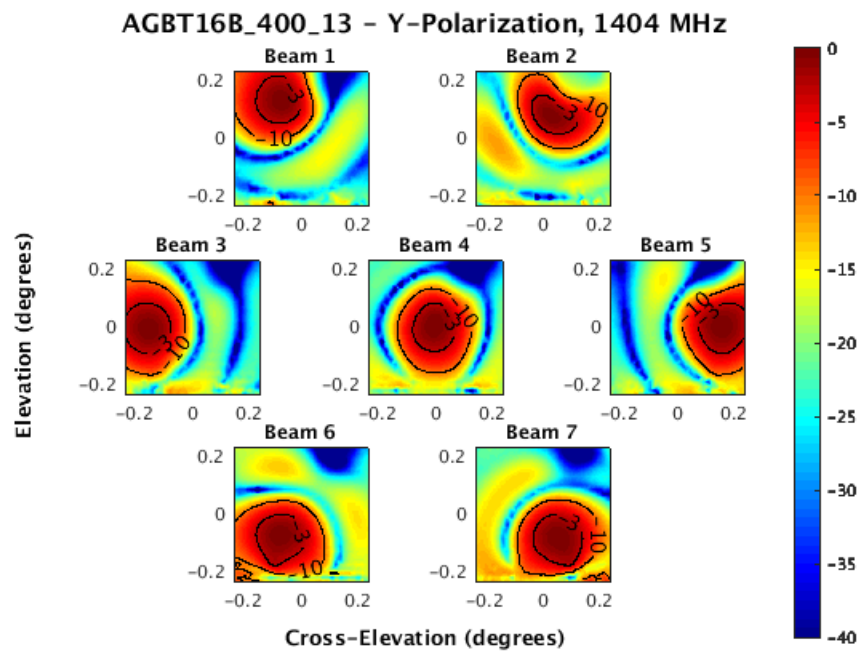




BEAM PATTERNS

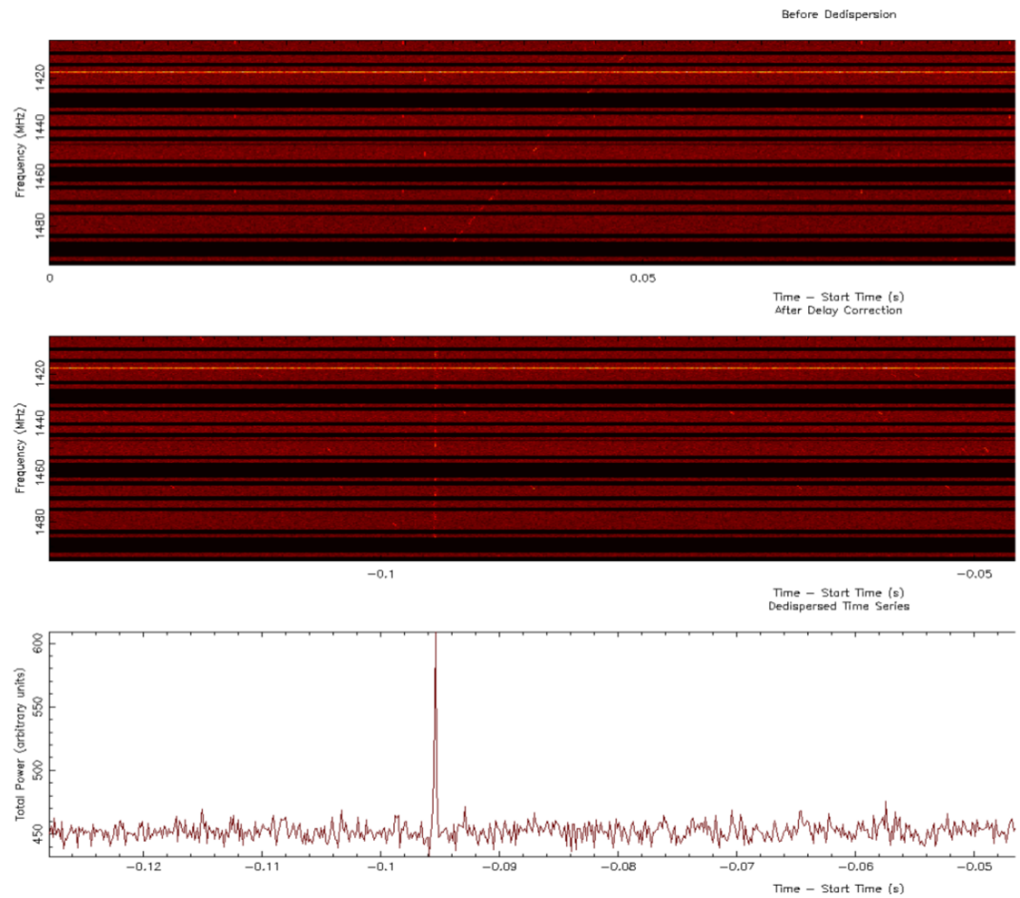
- X polarization (left) and Y polarization (right).
- Distortion in Y-polarization is due to malfunctioning elements.





PULSAR B1937+21 DETECTION

- The signal is seen moving across frequency as time samples advance (top).
- Dedispersion aligns the signal across time (middle).
- The data is integrated across frequency to produce the bottom plot.



CONCLUSION AND FUTURE WORK

- Conclusion
  - Conducted experiments in Green Bank WV that enabled the measurement of a T_{sys}/η of approximately 28 K, comparable to that of a single pixel horn feed.
  - Implemented signal processing code that enabled pulsar detection with the first cryogenic astronomical phased array feed (PAF).
- Future work
  - Implement a commensal mode with both real-time beamforming and correlation.
  - Generate weights with GPU after calibration scan.
  - Optimize GPU code to increase processing speed and improve data transfer between threads.