COMMISSIONING RESULTS AND FUTURE WORK WITH THE FOCAL L-BAND ARRAY ON THE GREEN BANK TELESCOPE (FLAG)

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BYU
Electrical Engineering
Computer Engineering

GREEN BANK OBSERVATORY

NRAO National Radio Astronomy Observatory

ARECIBO OBSERVATORY
PUERTO RICO
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OUTLINE

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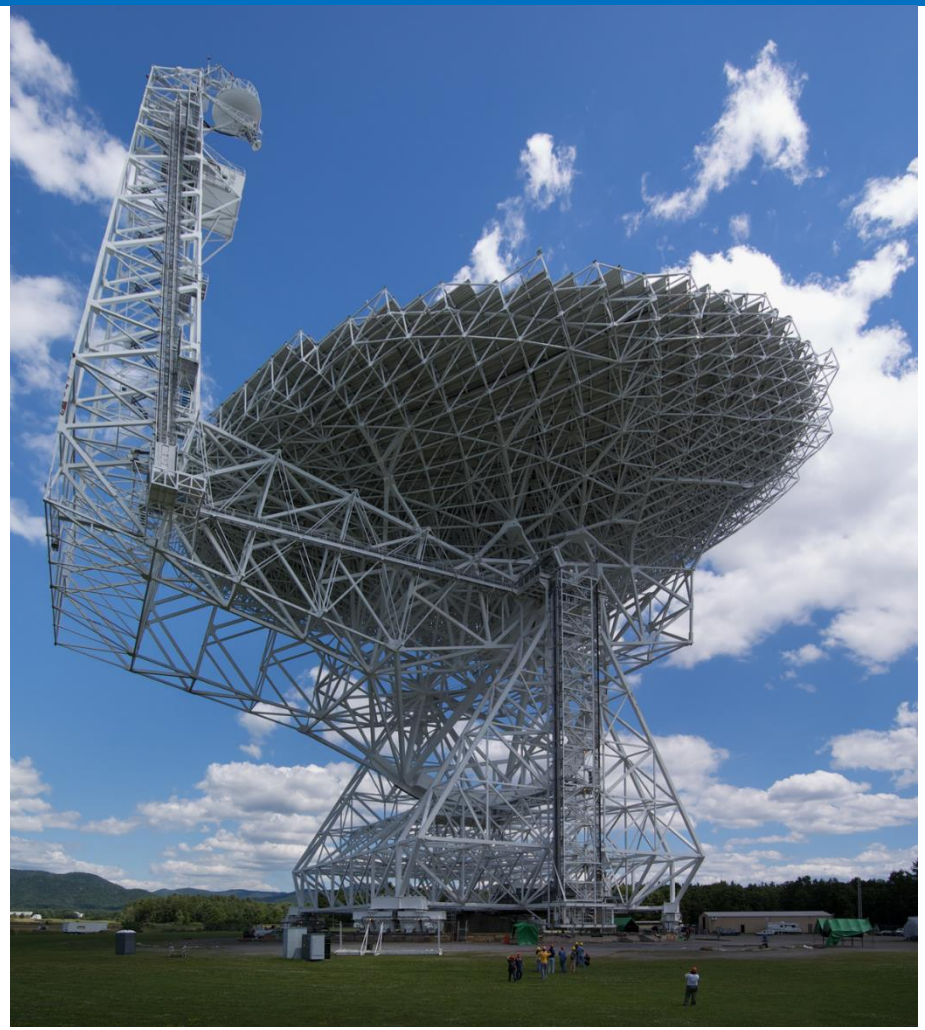
INTRODUCTION

- 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

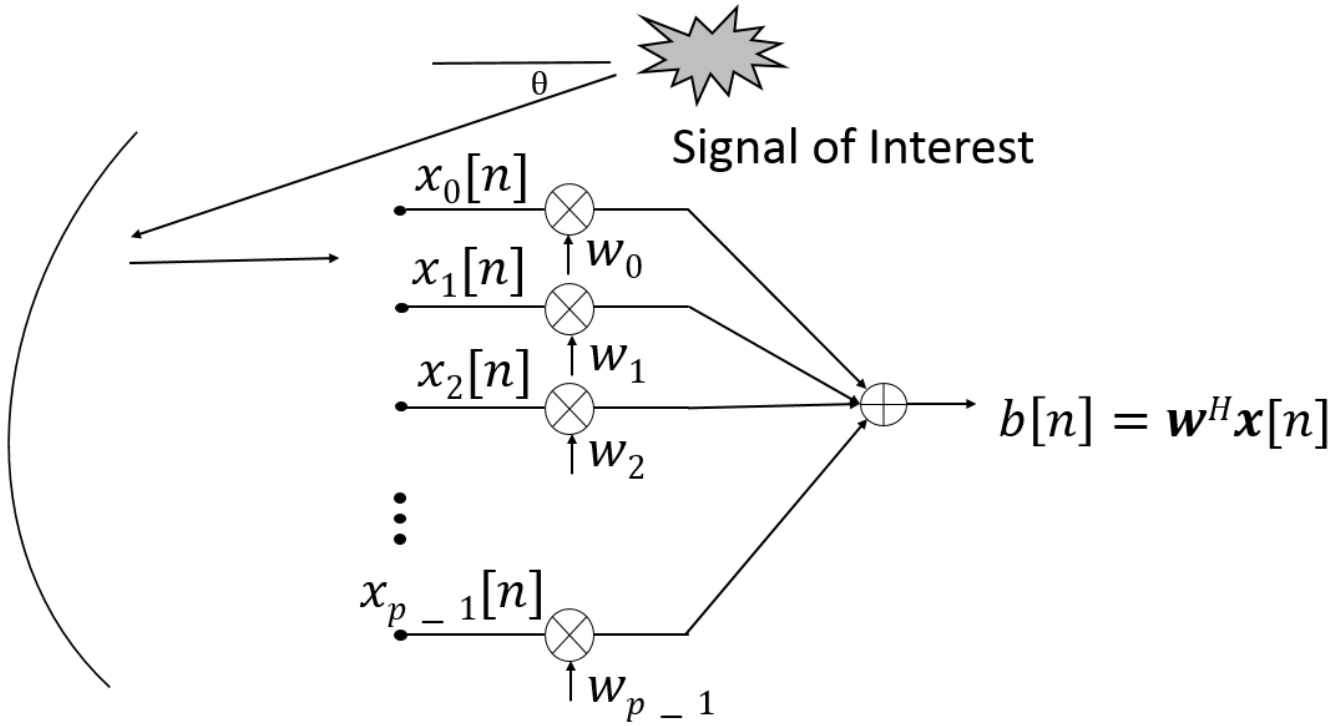
Phased Array Feeds (PAFs)

- A 2-D planar array of antennas placed at the focus of a large telescope dish that spatially samples the focal plane.
- Multiple pixels on the sky are synthesized in digital signal processing.
- Advantages:
  - Larger field of view than the traditional single-pixel horn feed.
  - Increased survey speed due to large field of view.
  - Optimized beamforming for different beam shapes and observation types.
  - 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.

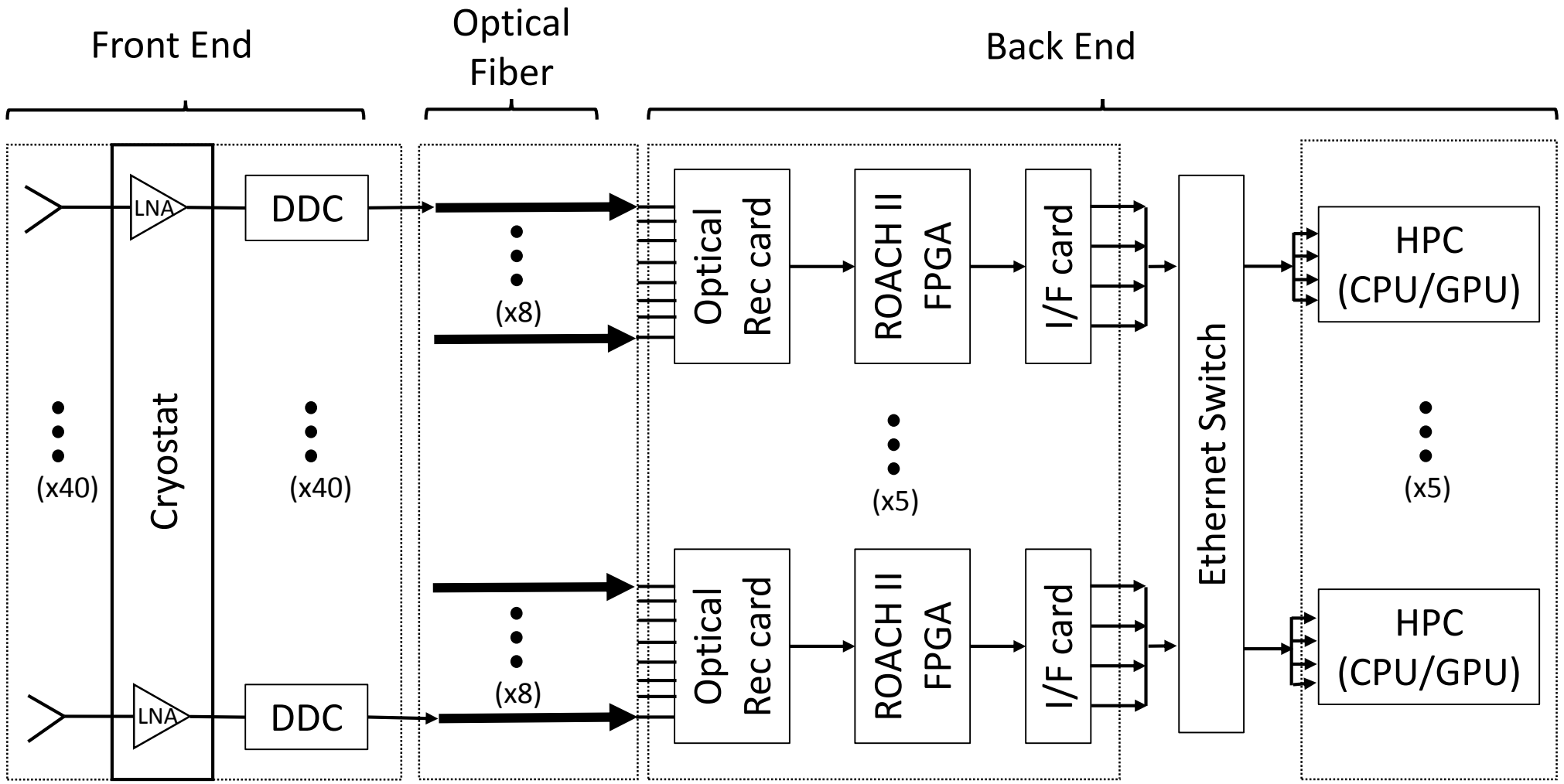
- Sample voltages received by each element.
- Multiplied by complex weight coefficient.
- Summed across elements to form beam in direction, θ.



FOCAL L-BAND ARRAY FOR THE GBT (FLAG)

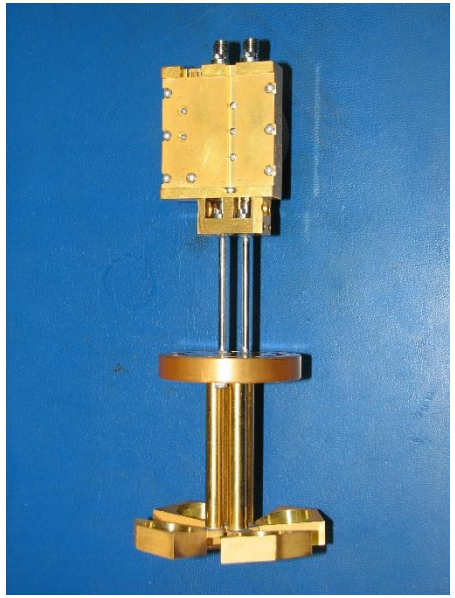
- Wide field astronomical PAF receiver with broadband signal processing and operational science observation capability.
- 19 dual-polarization elements.
- Front end analog bandwidth of approximately 300 MHz.
- Compared to an instantaneous signal processing bandwidth of 150 MHz.

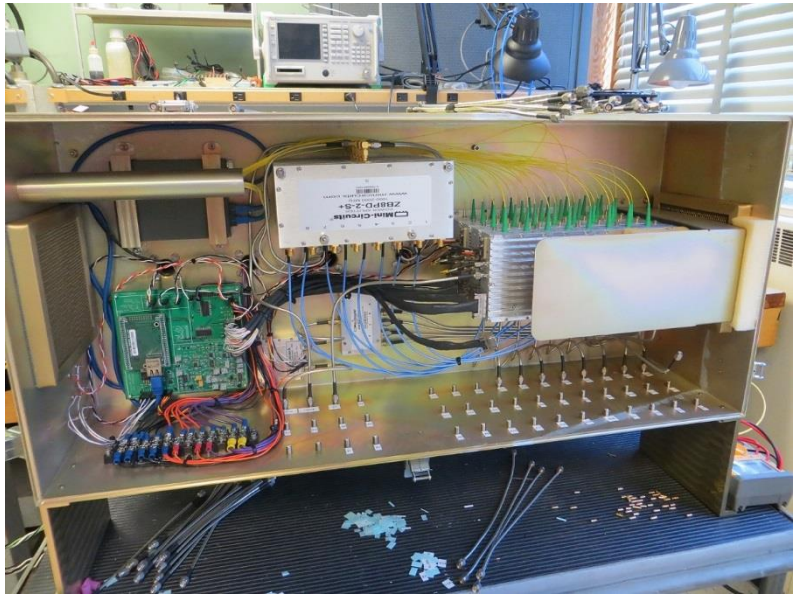
FLAG SYSTEM OVERVIEW



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.

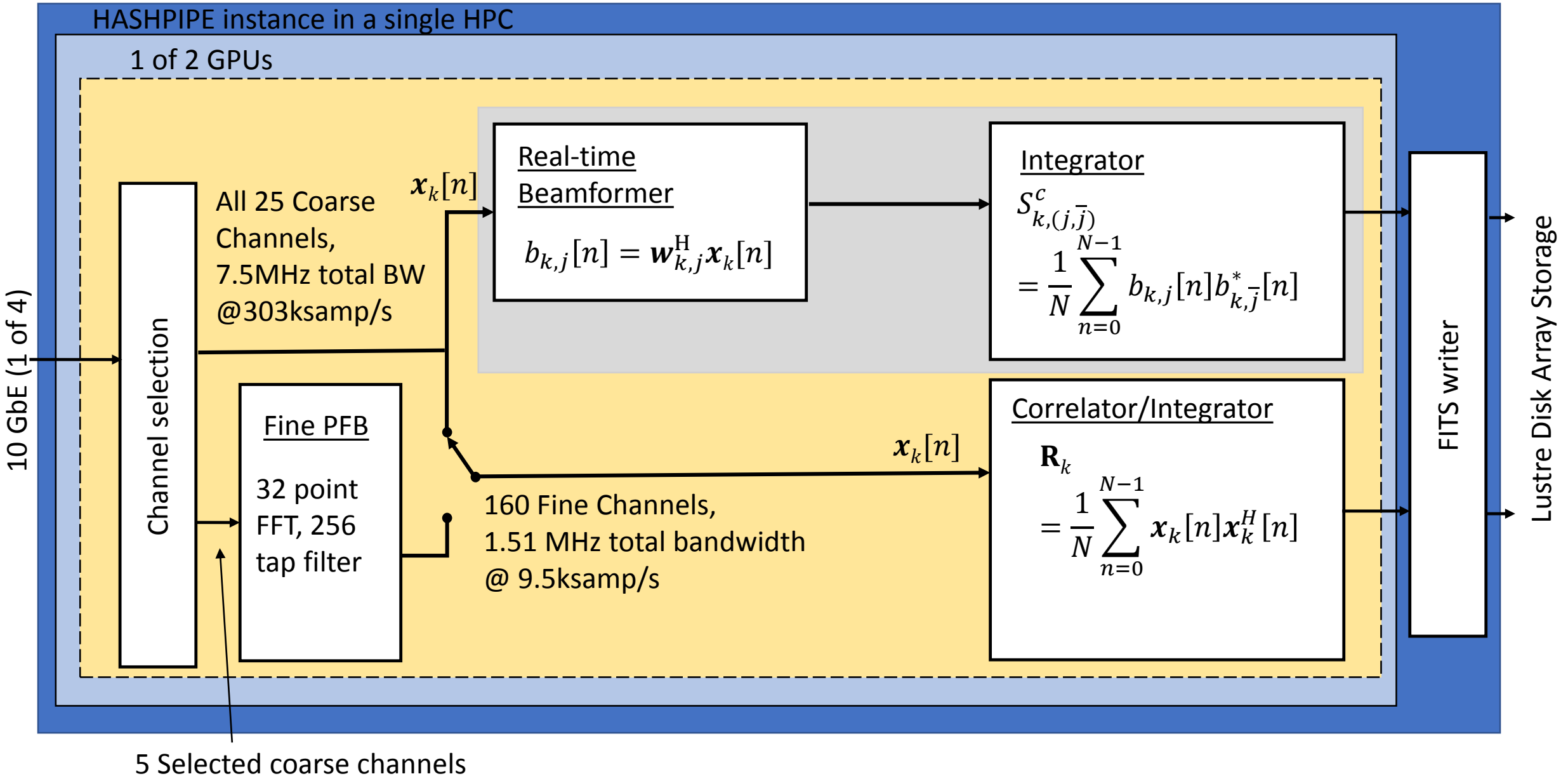




FLAG DIGITAL BACK END

- 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

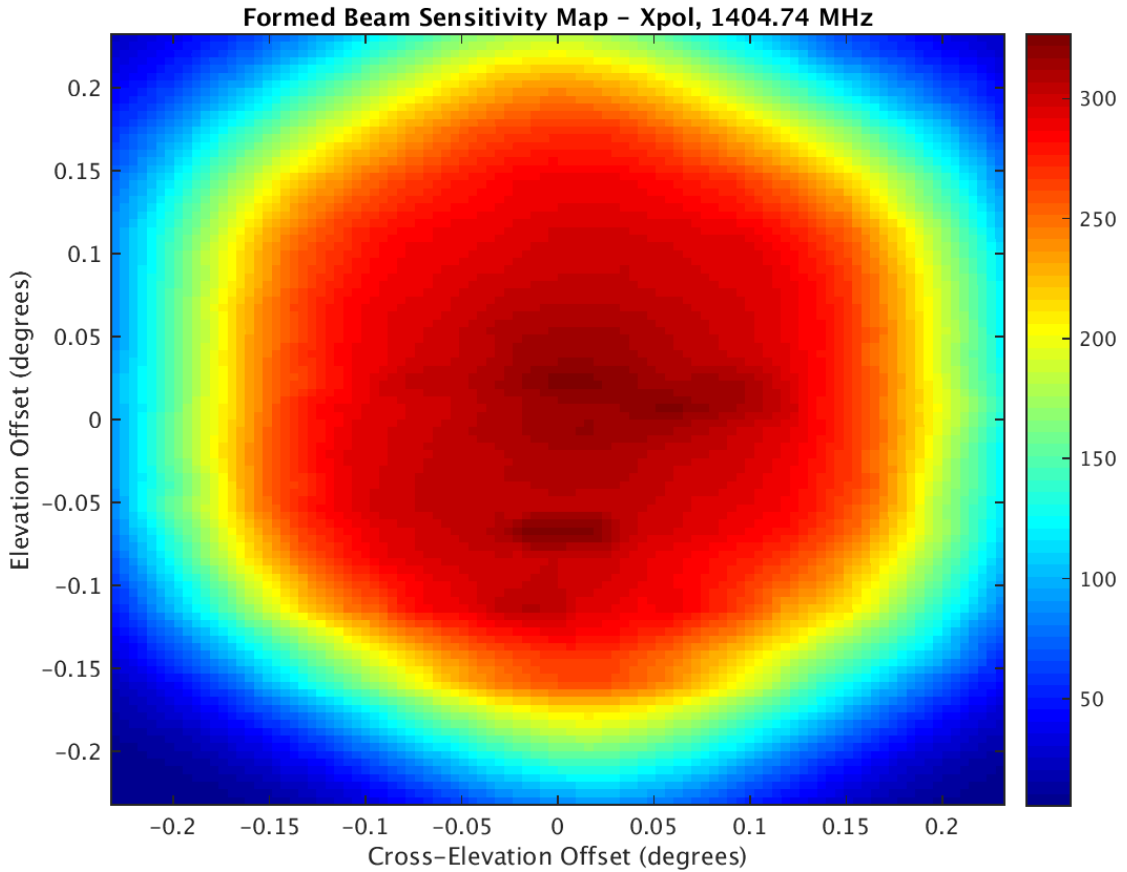


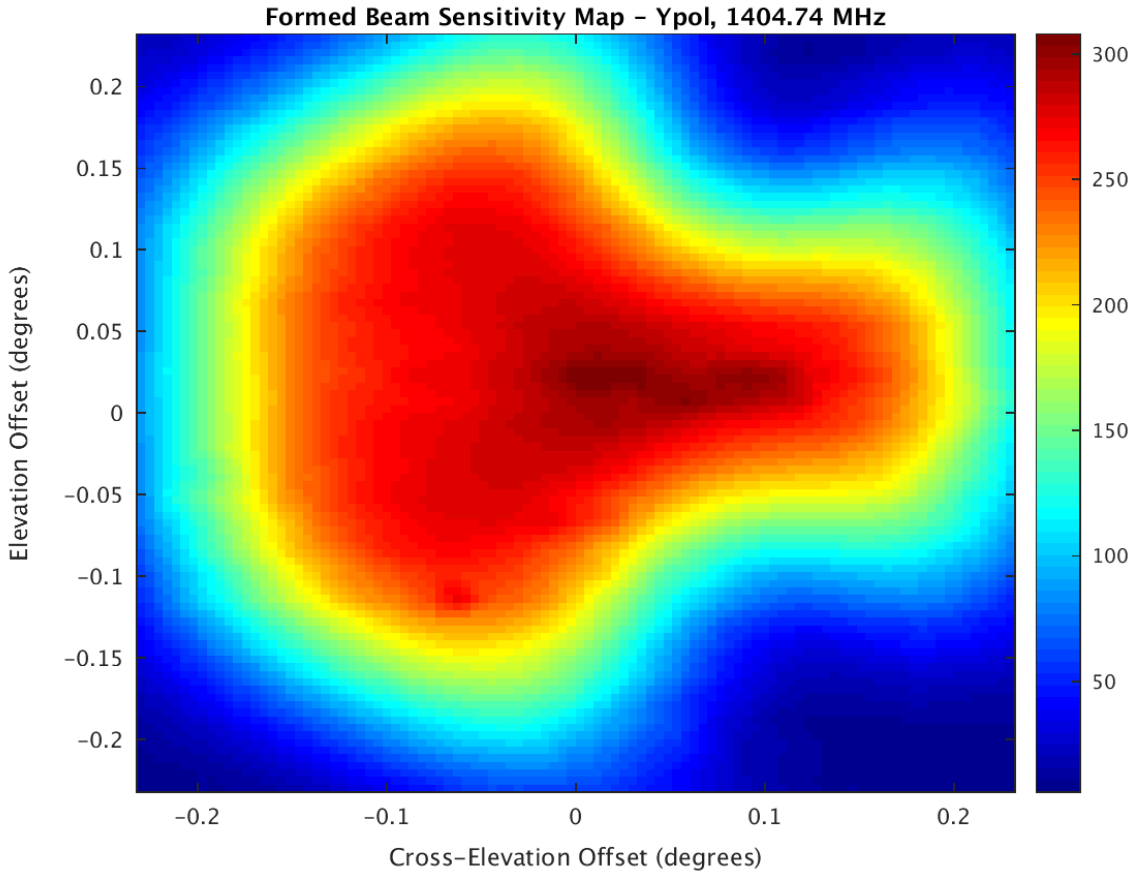
FLAG TESTING/COMMISSIONING

- Commissioning results acquired February 2019.
- Data was analyzed using:
  - The ratio of the system noise temperature to the antenna efficiency (T_{sys}/η).
  - Sensitivity maps which indicate sensitivity ($A_p\eta/T_{sys}$) at different coordinates within the field of view.
  - Beam patterns.
- T_{sys}/η of 24 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

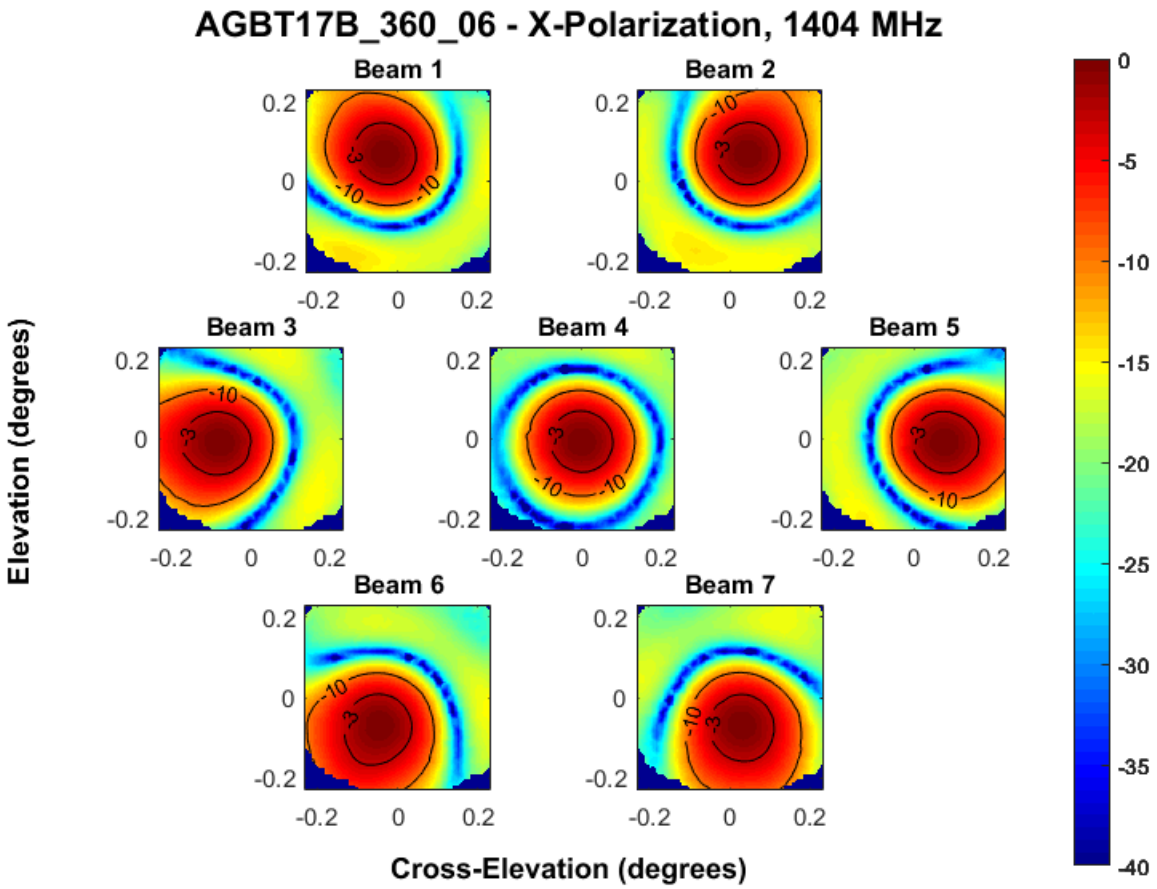
- X-polarization (left) and Y-polarization (right).
- Cross-elevation and elevation coordinates on the x and y axes respectively.
- Distortion in Y-polarization is due to malfunctioning elements.

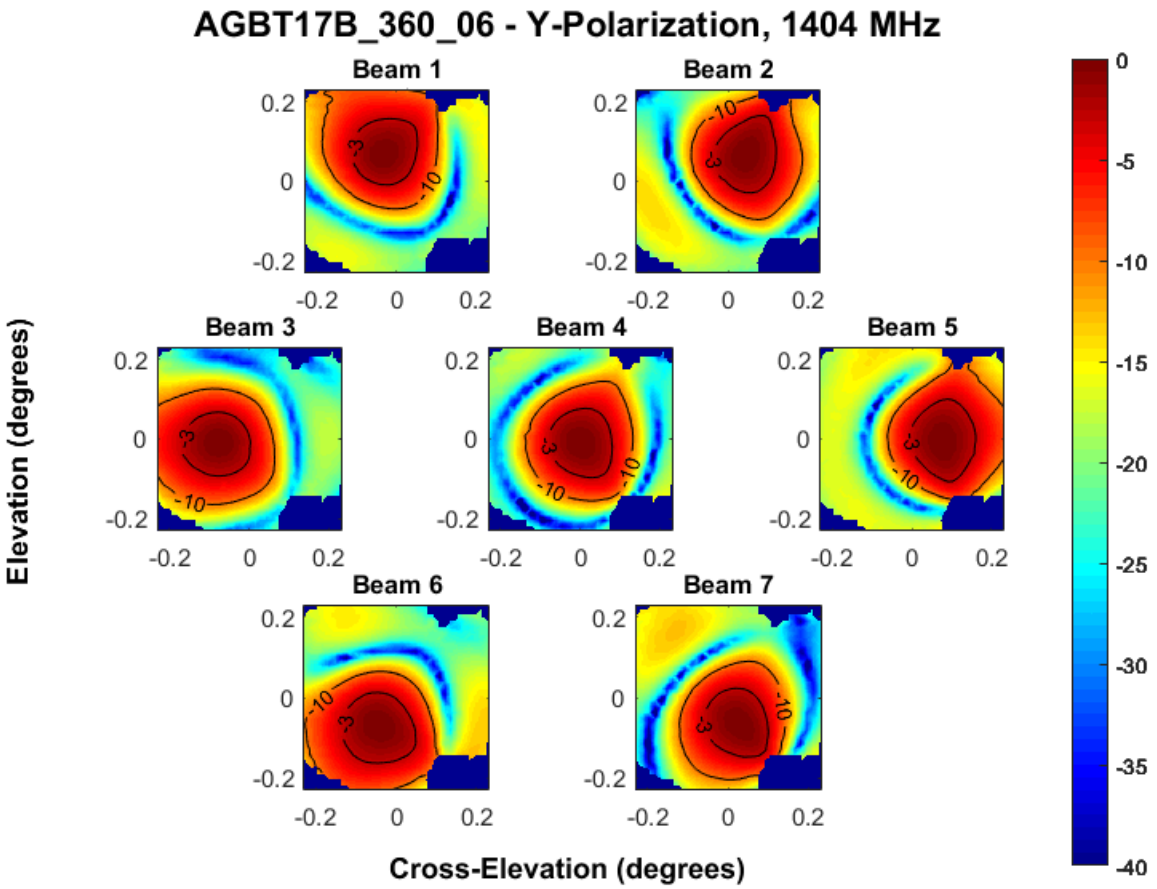




BEAM PATTERNS

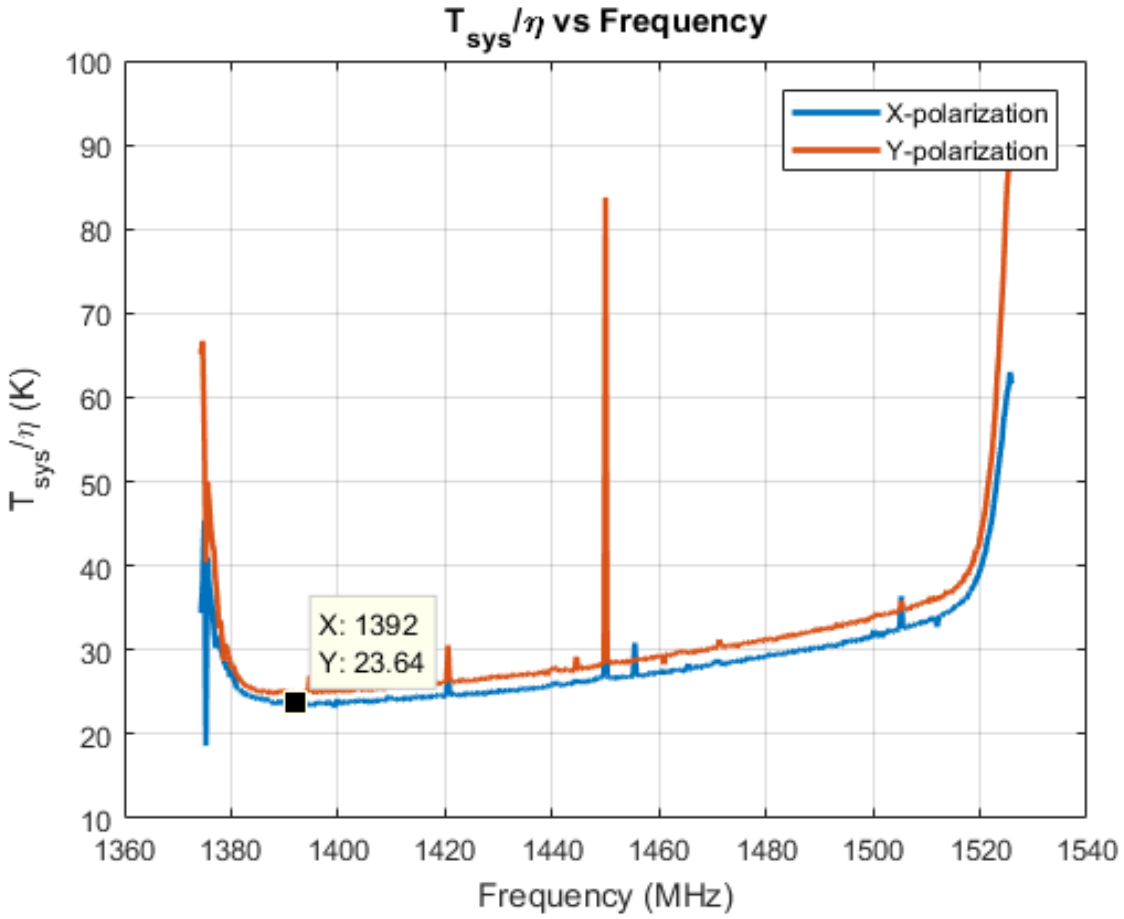
- X polarization (left) and Y polarization (right).





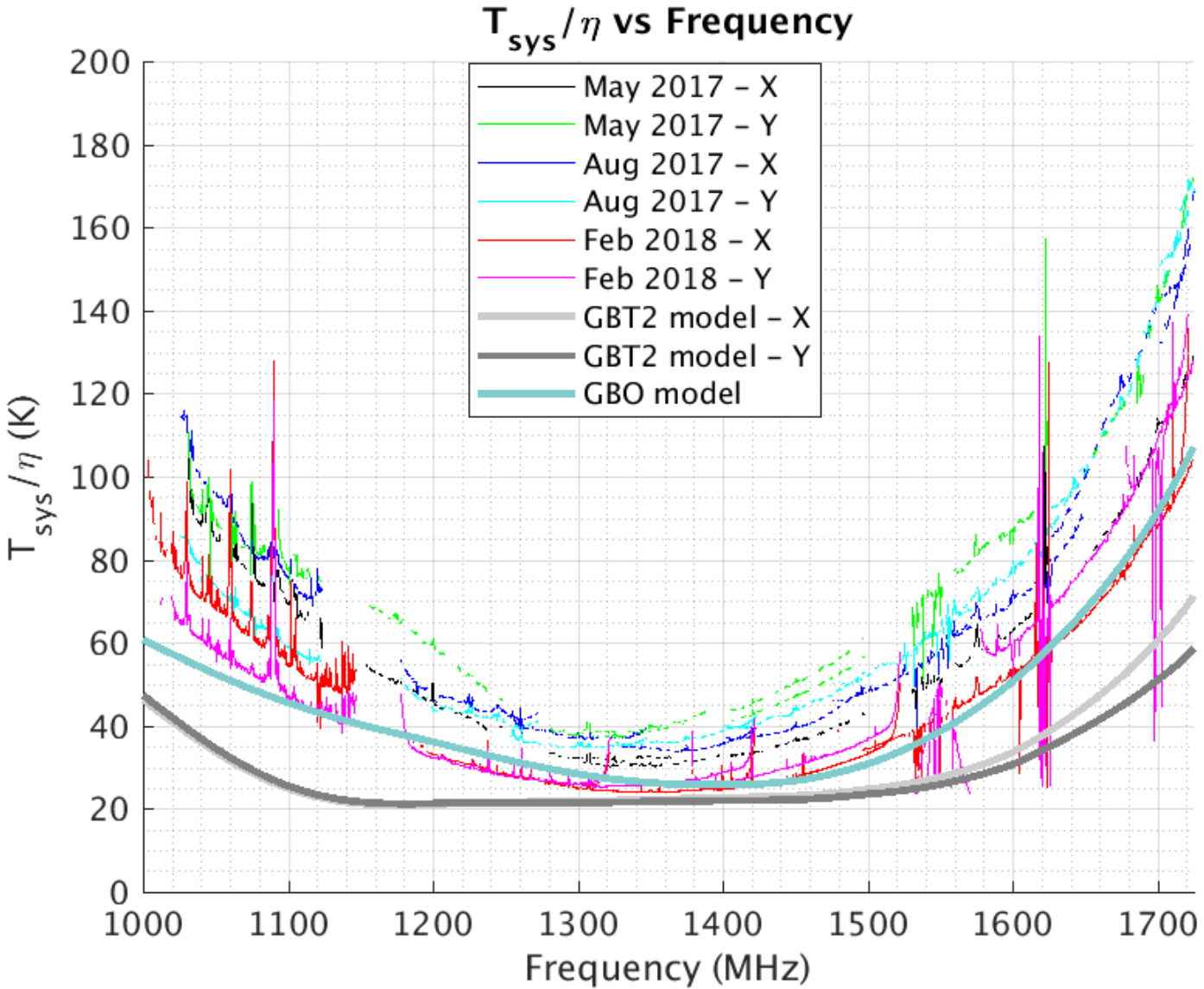
T_{sys}/η

- X and Y polarizations are shown in the figure.
- The plot shows the measured T_{sys}/η of 24 K at approximately 1392 MHz.



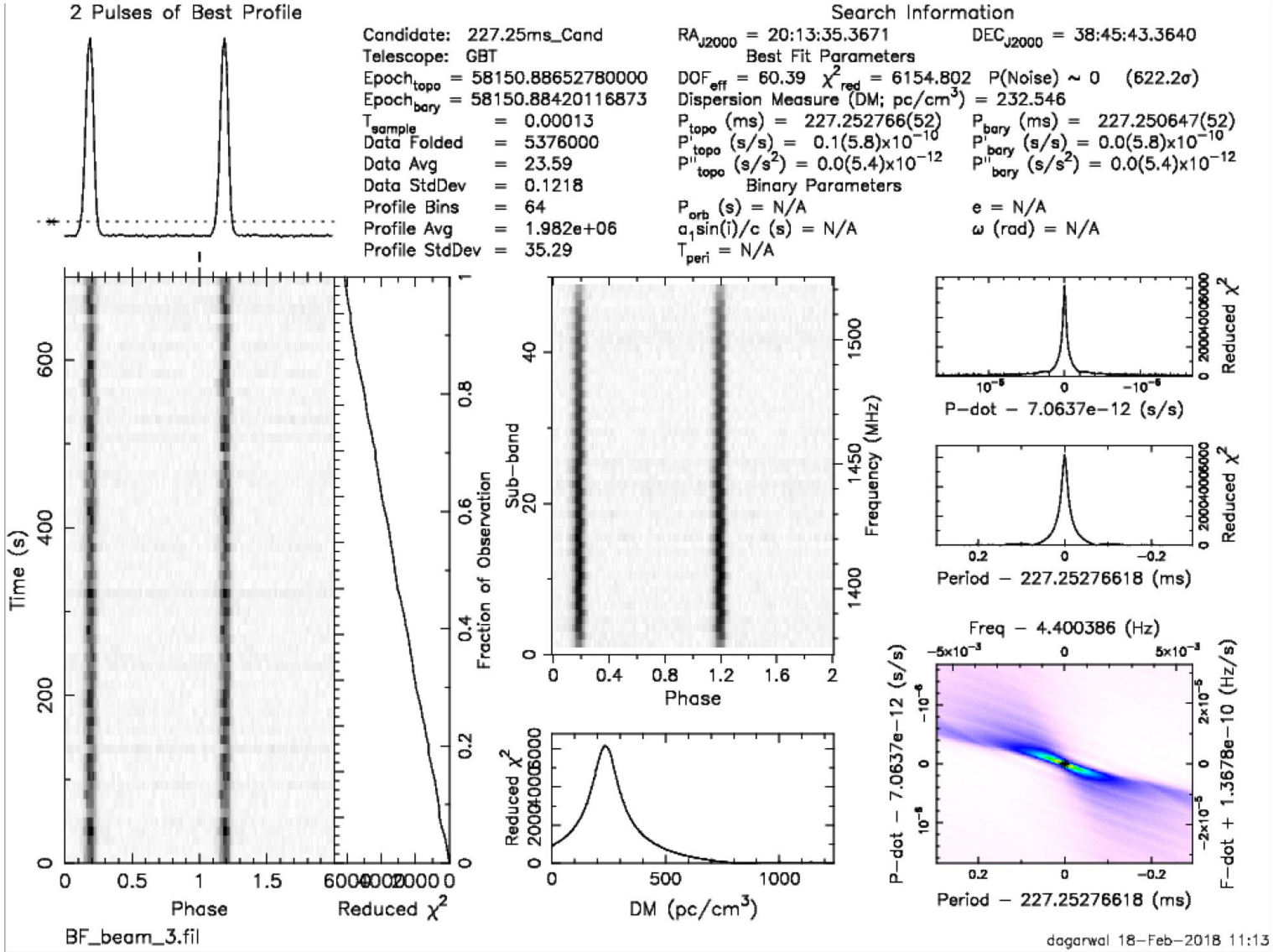
T_{sys}/η FULL BANDWIDTH

- The gaps are masking RFI and band edges from the instantaneous bandwidth in the plot.

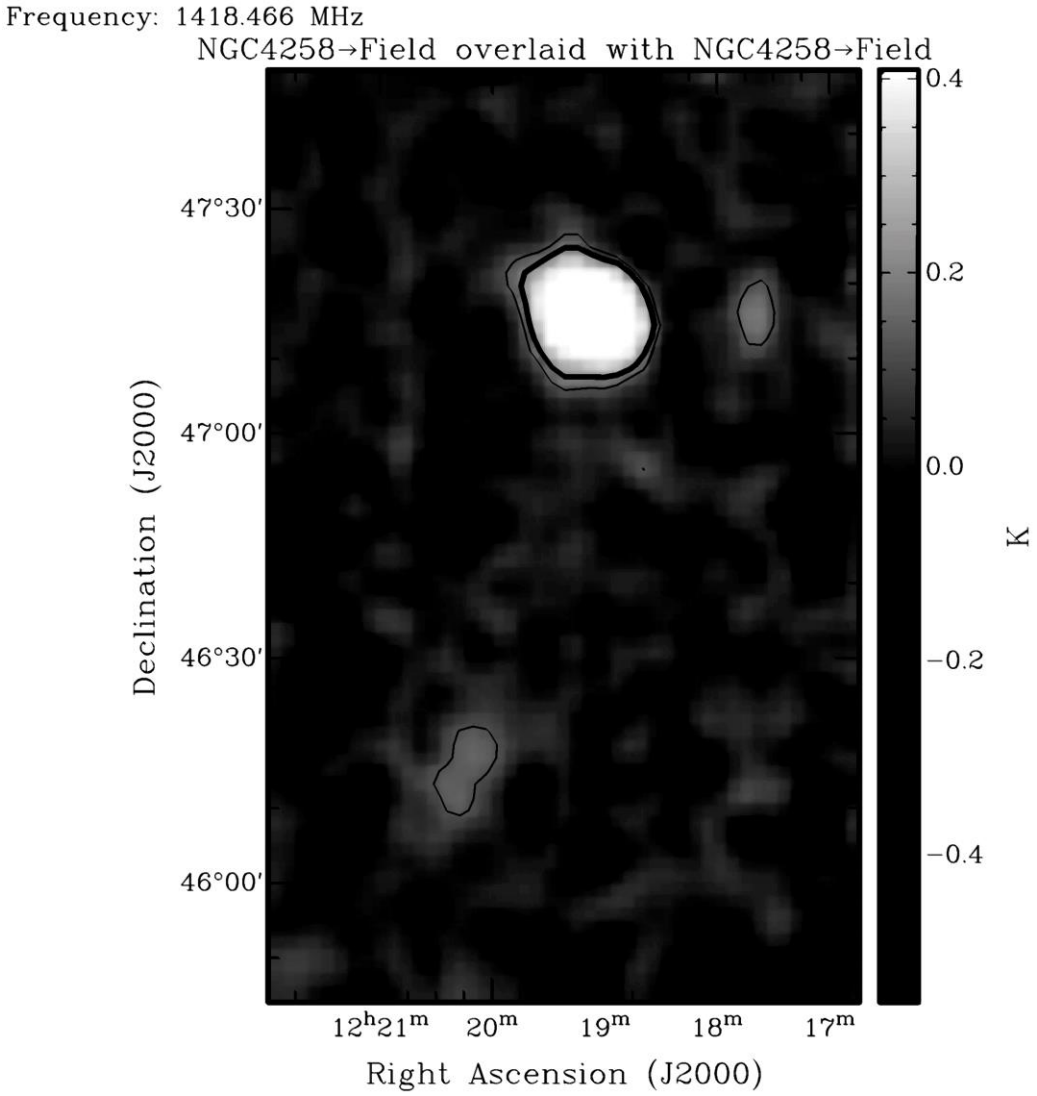


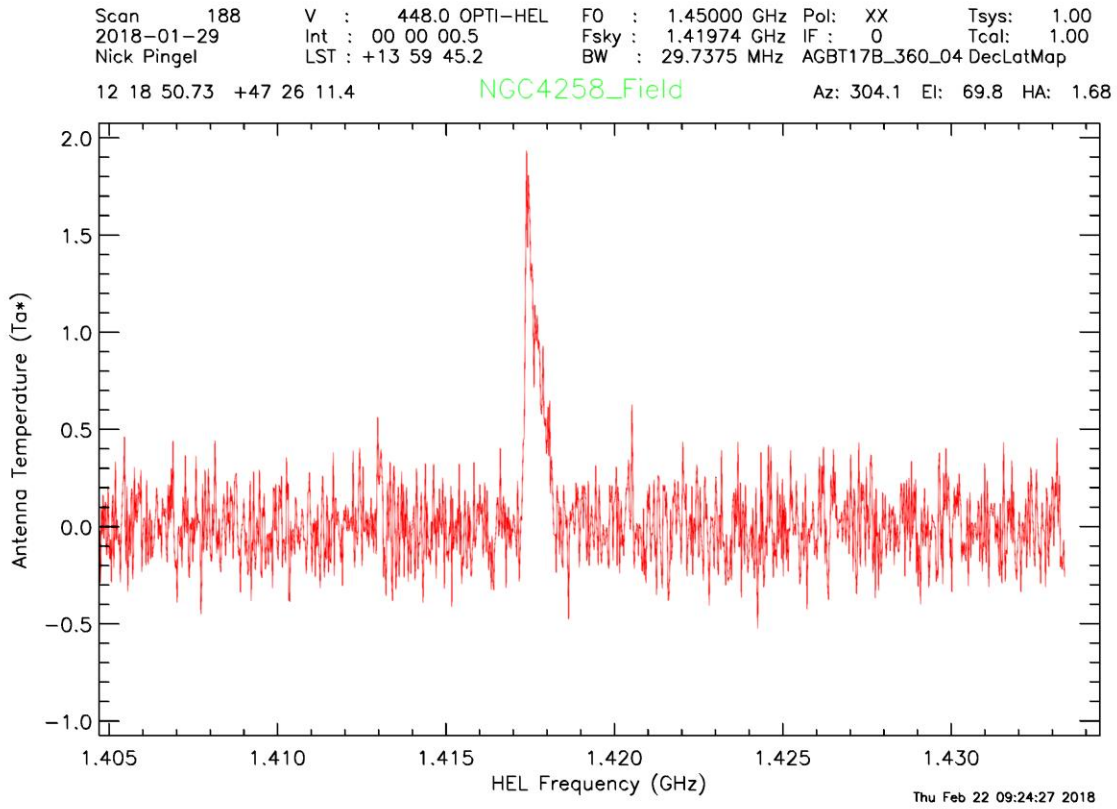
PULSAR B2011+38 DETECTION

- Known bright pulsar.
- Two important plots:
  - Time series plot of the pulsar folded to the pulse period (pulsar emission only at a single phase).
  - Pulsar emission seen in frequency space which shows the broadband radio emission from pulsars.



NGC4258 (HI SOURCE)





ADVANCED L-BAND PHASED ARRAY CAMERA FOR THE ARECIBO OBSERVATORY (ALPACA)

- Funded by U.S. National Science Foundation.
- Similar to FLAG, but larger and optimized for a different optical geometry.
- Hexagonal array.
- 80 dual-polarization elements.
- 20 HPCs (2 GPUs per HPC).
- 20 Xilinx RFSoC boards.
- 312 MHz Bandwidth (selectable within the 440 MHz band).
- T_{sys}/η goal of less than 30 K.

CONCLUSION

- Conducted experiments in Green Bank WV that enabled the measurement of a T_{sys}/η of approximately 24 K, comparable to that of a single pixel horn feed.
- Implemented signal processing code that enabled pulsar and HI source detection with the first cryogenic astronomical and most sensitive phased array feed (PAF) demonstrated to date.

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.
- Development of ALPACA is now underway at BYU, Cornell University and the Arecibo Observatory.