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Data Flow Design for a Gamma-Ray Telescope

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DATA FLOW DESIGN FOR A GAMMA-RAY TELESCOPE

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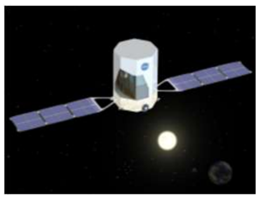
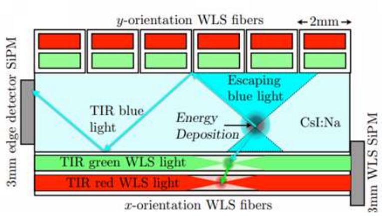
Background

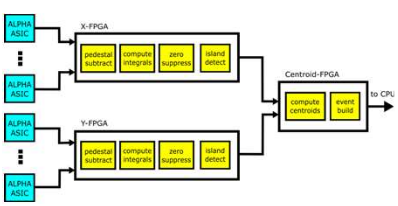
- The Advanced Particle-astrophysics telescope (APT) is a planned space telescope
- Detects gamma-ray bursts (GRB) and promptly communicate with other instruments for real-time follow-up observation
- FPGAs preprocess the raw data to be sent to the CPU



The telescope detects gamma-ray photons in space

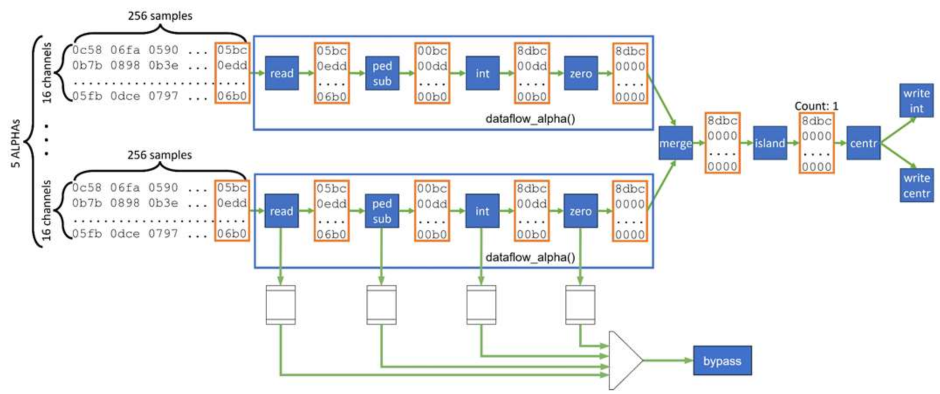


Photons enter the detector and light up fibers



Methods

- Add a bypass channel to the existing data to handle debugging and pair production events
- Use C++ and High-Level Synthesis to develop the FPGA design




```
void dataflow_alpha(const vec_uint16_16 * samples,
                    hls::stream<Header> & header_stm_in, // contains all read-only information
                    hls::stream<Header> & header_stm_out, // contains all read-only information
                    hls::stream<vec_int32_16> zeroed_integrals[NUM_ALPHAS],
                    hls::stream<vec_int32_16> raw_pair_data[NUM_ALPHAS],
                    const uint8_t banks[NUM_ALPHAS],
                    const uint8_t starting_sample_numbers[NUM_ALPHAS],
                    const int16_t base_addrs[NUM_ALPHAS],
                    const uint8_t alpha
                    ) {

#pragma HLS FUNCTION_INSTANTIATE variable=alpha

    hls::stream<vec_uint16_16> packet_samples;
    hls::stream<vec_int32_16> ped_sub_results;
    hls::stream<vec_int32_16> integrals;
```

```
Header::Header(vec_uint16_16 input_all_peds_in[NUM_ALPHAS][2*NUM_SAMPLES],
    for (int i = 0; i < NUM_ALPHAS; ++i) {
        for(int j = 0; j < 2*NUM_SAMPLES; ++j) {
            for(int k = 0; k < 16; ++k) {
                input_all_peds[i][j][k] = input_all_peds_in[i][j][k];
            }
        }
        for(int j = 0; j < 2*NUM_INTEGRALS; ++j) {
            bounds[i][j] = bounds_in[i][j];
        }
        for(int j = 0; j < NUM_INTEGRALS; ++j) {
            zero_thresholds[i][j] = zero_thresholds_in[i][j];
        }
    }
}
```

Accomplishments/Current Status

- Refactored the code to support stream-based inputs
- Built a bypass path to store a buffer of pedestal-subtracted data
- Changed metadata flow to move with main data packets

Future Work

- Creating additional bypass pathways and control logic for selecting a data stream
- Analyzing additional buffering requirements on overall FPGA
- Update packet definitions across the entire pipeline to be compatible with bypass
- Enable the FPGA-to-FPGA data communications, including accommodating the bypass path
- Enable the FPGA-to-network-to-embedded processor communications, also accommodating the bypass path

Lessons Learned

- Usage of high-level synthesis for FPGA layout
- Data flow and computation architecture (parallelism through pipelining)
- Advanced stream management in C++

Acknowledgements

Thank you to Roger Chamberlain, Marion Sudvarg and James Buckley

References

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Wenlei Chen, James H. Buckley et al. The Advanced Particle-astrophysics Telescope: Simulation of the Instrument Performance for Gamma-Ray Detection. In Proc. of 37th International Cosmic Ray Conference – PoS(ICRC2021), volume 395, pages 590:1–590:9, July 2021.

Marion Sudvarg, Chenfeng Zhao, Ye Htet, Meagan Konst, Thomas Lang, Nick Song, Roger D. Chamberlain, Jeremy Buhler, and James H. Buckley. 2024. HLS Taking Flight: Toward Using High-Level Synthesis Techniques in a Space-Borne Instrument. In Proc. of 21st International Conference on Computing Frontiers. ACM, 12 pages. https://doi.org/10.1145/3649153.3649209