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A Low-Cost, Low-Power Media Converter Solution for Next-Generation Detector Readout Systems

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HEP data acquisition systems are often built from high-end FPGAs. As such systems scale in the HL-LHC era, severe underutilization of FPGA transceivers can occur because frontend links prioritize radiation hardness and power consumption over raw data bandwidth. This work evaluates recently introduced low-power, low-cost FPGA devices as an alternative building block for future readout architectures. We implement a readout backend on FPGA where the frontend protocol is based on the Low-Power GigaBit Transceiver (lpGBT) and the readout protocol is based on 10 Gigabit Ethernet, using the LHCb Run 4 RICH detector as a practical case study.

Summary (500 words)

The next-generation of detectors in Large Hadron Collider (LHC) experiments will require higher bandwidth readouts, widely using radiation-hard Low Power GigaBit Transceiver (lpGBT) links. Current designs rely on expensive, high performance FPGAs to interface with the readout systems. However, our design offers a compact, resource-efficient smart media converter aiming at translating lpGBT to Ethernet.

Within our converter architecture, each lpGBT link feeds a pipeline where lpGBT words are buffered to form a packet with configurable size to reduce the impact of UDP/IP header overhead. Packets are subsequently transmitted on a dedicated 10 Gigabit Ethernet (10GbE) link. The choice of 10GbE aligns with lpGBT data rates and is compatible with most low-cost FPGA transceiver speeds and hard IPs, ensuring both compatibility and cost effectiveness. Notably, the entire data pipeline has been constructed using open-source, vendor-independent cores, enhancing portability across different FPGA devices.

A key feature of our media converter is the integration of a soft microcontroller unit (MCU), facilitating remote control, monitoring, and configuration via MQTT over a dedicated 1GbE interface.

This design represents a significant improvement in terms of flexibility, scalability, and modularity compared to existing systems. It is well-suited to a range of applications, from basic testbench and test beam setups, where direct interfacing with a network interface card is feasible, to large-scale detector systems, where multiple converters can be aggregated using off-the-shelf Ethernet switches.

The hardware implementation and testing phase utilized an AMD Artix Ultrascale+ DevKit, capable of accommodating up to four lpGBT links. Results demonstrate that full throughput of 9 Gbps can be achieved with packet sizes exceeding 3kB, with no backpressure. The low resource usage indicates the possibility of adding some basic data processing on device.

Emulation of a frontend is done using a Zynq Ultrascale+ and a VLDB+ board, simulating the LHCb Run 4 RICH readout (fastRICH) data encoding. Once the real frontend ASIC will be available, the test harness will already be available and tested, reducing the time needed for setup and debugging.

Author: PERRO, Alberto (Universite d'Aix-Marseille III (FR))

Co-authors: VODNIK, Mitja (Jozef Stefan Institute (SI)); DURANTE, Paolo (CERN)

Presenter: PERRO, Alberto (Universite d'Aix-Marseille III (FR))

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