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Efficient Backend Development for Detectors and Radio Astronomy

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Field-Programmable Gate Arrays (FPGAs), leveraging their exceptional parallel processing capabilities and real-time performance, are indispensable in radio frequency (RF) signal acquisition and processing. They are widely utilized in cutting-edge applications such as radio astronomy signal processing and low-temperature detector systems, including Kinetic Inductance Detectors (KIDs) and Transition Edge Sensors (TES). These domains demand adaptability to rapidly changing experimental requirements during development, while also requiring seamless integration into large-scale, high-performance systems for practical deployment.

In laboratory settings, FPGA design encounters significant challenges, including highly variable data acquisition specifications, frequent iterations of signal processing algorithms, and constraints imposed by limited hardware resources. These factors often lead to prolonged development cycles and inefficiencies. Consequently, optimizing the organization of hardware and software design resources to enhance development efficiency, while aligning with the dynamic and resource-constrained nature of laboratory applications, emerges as a critical and valuable research question.

This work details the author’s efforts in advancing FPGA development to simultaneously support radio astronomy and low-temperature detector research within a laboratory environment. Specific applications include backend for single-antenna and antenna arrays for radio astronomy, alongside TES and KIDs readout systems for detectors. By implementing modular design principles and reusable frameworks, this study explores strategies to maximize design efficiency across these diverse projects. Preliminary results demonstrate significant improvements in R&D efficiency, such as reduced development time and enhanced adaptability, offering a scalable approach that bridges laboratory prototyping and future large-scale implementations.