URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

Continuous Integration Testing of Real-time Signal Processing and Control for the SKA Low Correlator and Beamformer

A.B. Bolin*(1), S. Chiang(1), G.C. Babich(1), G.A. Hampson(1), B. Bacic(1),
K.J. Bengston(1), G. Jourjon(1), D. Humphrey(1), J.D. Bunton(1), Y. Chen(1)
(1) CSIRO, Space & Astronomy, Cnr Vimiera and Pembroke Roads, Marsfield, NSW, Australia, 2122
email: andrew.bolin@csiro.au

The Square Kilometre Array (SKA) Low telescope's Correlator and Beamformer (Low CBF) comprises a number of FPGA signal processing cards, 100 Gbps Ethernet (100GbE) network, and associated software [1]. Here we present the automated "Continuous Integration" (CI) methodologies used to build the FPGA firmware and perform validation and testing of Low CBF. Our methods are modular, re-usable, and open-source.

Low CBF signal processing is performed on an array of Xilinx Alveo FPGA cards, connected together via 100GbE links routed by P4 network switches. The signal processing is "atomic" - it is broken into discrete frequency bands, such that a single FPGA is (generally) able to perform end-to-end processing for a quanta of input bandwidth/stations, with four firmware "personalities" used to perform different real-time signal processing operations [1]. The atomic design of Low CBF hardware lends itself to automated testing. Rather than build/simulate a full telescope, we can instead generate network packets representing inputs to, and expected outputs from, a single FPGA. In order to accurately stream/capture real-time data at up to 100Gbps, we have developed general-purpose 100GbE "Customisable Network Interface Card" (CNIC) firmware which also runs on an Alveo FPGA card [2]. Using this firmware, one P4 switch, and a small number of FPGA cards, we can run a battery of automated tests against signal processing firmware and various layers of control software.

The SKA has chosen GitLab as their source code repository and CI platform. GitLab provides sophisticated CI features including automated "pipelines" (sequences of scripts), allows the use of cloud-based or self-hosted "runners" to execute jobs, and has previously been used for FPGA applications [3]. Our CI pipeline configuration makes use of inheritance and a layered design such that low-level common tasks need only be specified once while allowing flexibility for unusual scenarios. This flexibility enabled the scheme to be easily adopted by the Parkes Radio Telescope "CryoPAF" project [4], despite architectural differences.

CSIRO hosts a Prototype System Integration (PSI) facility at Marsfield, which includes a Kubernetes cluster accessible via GitLab runner, P4 switch, and FPGA host server with sufficient FPGAs to run multiple CNICs and the signal processing firmware under test. Mechanisms were implemented to permit concurrent use of PSI hardware for both manual debugging and automated CI testing, such as "reserving" FPGAs so Kubernetes does not schedule jobs to them while they are used for non-Kubernetes debugging work.

Overall, our CI build and test framework provides early detection of regressions, verification of firmware correctness and real-time performance, and checking of control system integration, at every incremental code change. Ultimately this will lead to faster commissioning and future upgrades of the SKA Low CBF, but also radio telescope signal processing systems more generally.

References

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[3] C. Serrano et al., "Hardware-in-the-loop Testing of Accelerator Firmware," in *17th Int. Conf. on Acc. and Large Exp. Physics Control Systems (ICALEPCS2019)*, 2019, doi: 10.18429/JACoW-ICALEPCS2019-TUAPP01.

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