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Frontiers in Technology: Evolution, Trends, and Transformation of Digital Receivers for Radio Astronomy/Cosmology applications

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Digital receivers in radio astronomy have made substantial strides by integrating cutting-edge technologies such as Analog-to-Digital Converters (ADCs), Field-Programmable Gate Arrays (FPGAs), Graphics Processing Units (GPUs), and Radio Frequency Systems on Chip (RFSoCs) to enhance the sensitivity and imaging resolution of astronomical observations. ADCs facilitate the digitization of analog signals from antennas; FPGAs perform real-time signal processing tasks like digital filtering, channelization, and beamforming and GPUs accelerate complex computational algorithms. On the other hand, RFSoCs integrate a range of functionalities, including RF data converters, programmable logic (PL), ARM Cortex processors, and high-speed transceivers within a single chip. This amalgamation enhances system performance while minimizing physical footprint and reducing power consumption, thereby providing a compact and power-efficient solution that is highly suitable for integration into digital receivers for experimental astronomy applications. Moreover, optical fiber technology has revolutionized high-speed data transfer by significantly increasing bandwidth and minimizing signal loss, enabling faster and more dependable data transfers.

At the forefront of these technological developments are the pioneering efforts towards the indigenous development of the digital receiver instrumentation for interferometer arrays, starting with Giant Metrewave Radio Telescope (GMRT), Ooty Radio Telescope (ORT), Sky Watch Array Network (SWAN) with multi-band receiver, and subsequent developmental efforts towards Murchison Widefield Array (MWA) leading to Square Kilometre Array (SKA); all these initiatives aimed to achieve diverse scientific objectives. The development of a new pulsar instrumentation array at the Gauribidanur Radio Observatory (GBD) follows this. Advancements in precision spectral radiometers based on digital correlation spectrometers in cosmology experiments, such as Shaped Antenna measurement of the background RAdio Spectrum (SARAS), Probing ReionizATion of the Universe using Signal from Hydrogen (PRATUSH), and Array of Precision Spectrometers for Epoch of Recombination (APSERa), aim to detect subtle spectral distortions in Cosmic Radio and Microwave Backgrounds spanning epochs from Recombination to Reionization. The development of next-generation Cosmology/radio astronomy with RFSoC Integrated generic Signal Processing platform (CRISP), a custom-designed platform, aims to enhance system performance, flexibility, and scalability with its compact, robust design, leveraging Size, Weight, and Power (SWaP) attributes. This presentation delves into the transformative evolution of digital receiver technology used in radio astronomy and cosmology experiments, elucidating the hardware and signal processing architectures and their current status.

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