Digital high-resolution wide-band Fast Fourier Transform Spectrometer

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Since a few years digital Fast Fourier Transform Spectrometers (FFTS), based on high-speed analog-to-digital converter (ADC) and high-performance field-programmable gate array (FPGA) chips, have become a standard for heterodyne receivers, particularly in the millimeter and submillimeter wavelength range [1]. The high dynamic range of today's high-speed ADCs with 10 or 12-bit allows observing strong continuum sources and bright maser lines without signal loss. FFT spectrometers are calibration- and aging free and operate very stable with long Allan-variance times of several 1000 seconds. In addition, FFT spectrometers have proven to be extremely reliable and robust, even in very harsh environmental conditions such as at the APEX telescope at an altitude of 5100 meters or on board SOFIA [2].

At the Max-Planck-Institut für Radioastronomie, the FFTS technology has been advanced over the last 15 years from 50 MHz to 4 GHz instantaneous bandwidth today. Our latest dFFTS4G spectrometer enables spectral analysis of two synchronously sampled signal inputs with an instantaneous bandwidth of 2 x 4 GHz with 2 x 64k spectral channels on one single 160 x 100 mm euro-sized board. Up to eight dFFTS4G boards can be housed in one 19” crate together with power-supplies and one FFTS-controller, so that a total bandwidth of 64 GHz per crate can be processed. Figure 1 shows a photo of the dFFTS4G spectrometer board.

Because even the fastest ADCs available today are not yet sufficient for broadband applications in radio astronomy, two 4 GS/s ADCs are time-interleaved on the dFFTS4G board to synthesize the behavior of an 8 GS/s converter. The main challenges with time-interleaving are accurate phase alignment of sampling-clock edges between channels and compensating for manufacturing variations that inherently occur between ADC chips. Accurately matching the gain, offset, and clock phase between separate ADCs is very challenging, especially because these parameters are frequency-dependent. For the dFFTS4G we optimized our adaptive FPGA-based calibration routine that measures an injected fixed frequency line and calculates the best parameter for gain, offset and clock phase. Applying this calibration scheme, no interleaving artefacts are noticed, even in long integrations.

The design of a new generation of FFT spectrometer for the requirements of future heterodyne multi-pixel receiver arrays, such as CHAI for CCAT-prime, is the goal of our further FFTS development. Especially with large array receivers, the simplest possible system layout of all components is particularly important so that these projects can be realized at all. In particular, the analog mixing of the IF bandwidth (4 – 8 GHz) to baseband (0 – 4 GHz), which is still required today, is to be eliminated. The availability of new RF-ADCs, which can sample analog signals from DC to 8 GHz, enables direct bandpass sampling and thus significantly simplified analog IF processing for future heterodyne receivers.

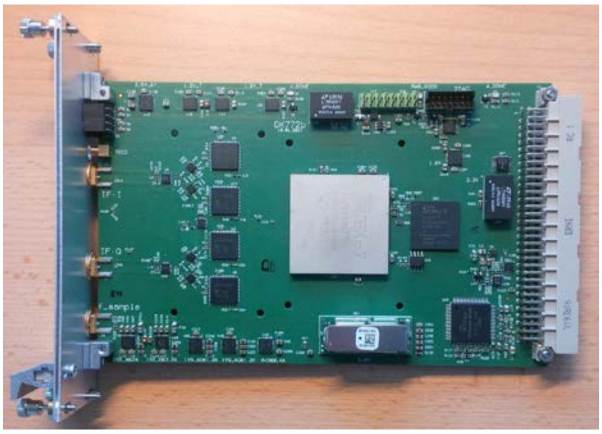

Fig. 1. Photograph of the dFFTS4G spectrometer board. The dFFTS4G uses four 12-bit 4 GS/s ADCs (TI ADC12D4000) and a high-performance Xilinx Virtex-7 960 FPGA for digital signal processing. Two ADCs each represent an ADC pair and sample the same input signal with 180 degree phase shift. By this time-interleave method an 8 GS/s ADC can be built up, which can acquire 4 GHz signal bandwidth.

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