The Next Generation of Fast Fourier Transform Spectrometers

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Abstract

We present our second generation of broadband Fast Fourier Transform Spectrometers (FFTS), optimized for radio astronomical applications. We have developed new analyzer boards, making use of the latest versions of GHz analog-to-digital converters and the most complex FPGAs commercially available today. These state-of-the-art chips have made possible to build digital spectrometers with coherent bandwidths of 1.5 GHz & 8192 frequency channels.

To simplify the combination of many analyzer cards into an array-FFT spectrometer, the novel board includes a complete 100 Mbit/s Ethernet interface. Precise time stamping of the processed spectra is realized by an on-board GPS/IRIG-B time decoder. The compact FFTS board (100 x 160 mm) operates from a single 5 Volt source, includes a flexible ADC clock synthesizer, and dissipates less than 20 W.

Unlike the conventional windowed-FFT processing, a more efficient pre-processing algorithm has been developed with significantly reduced frequency scallop loss, less noise bandwidth expansion, and faster sidelobe fall-off.

The new spectrometer board has been field-tested at the APEX telescope, and we present a first 1.5 GHz wide monolithic spectrum observed in October this year.

Spectrometer Technology

The rapid increase in the sampling rate of commercially available analog-to-digital converters (ADCs) and the increasing power of field programmable gate arrays (FPGAs) chips has led to the technical possibility to directly digitize the down-converted intermediate frequency (IF) signals of coherent radio-receivers, and to transform the digital signal stream into a power spectrum in real-time.

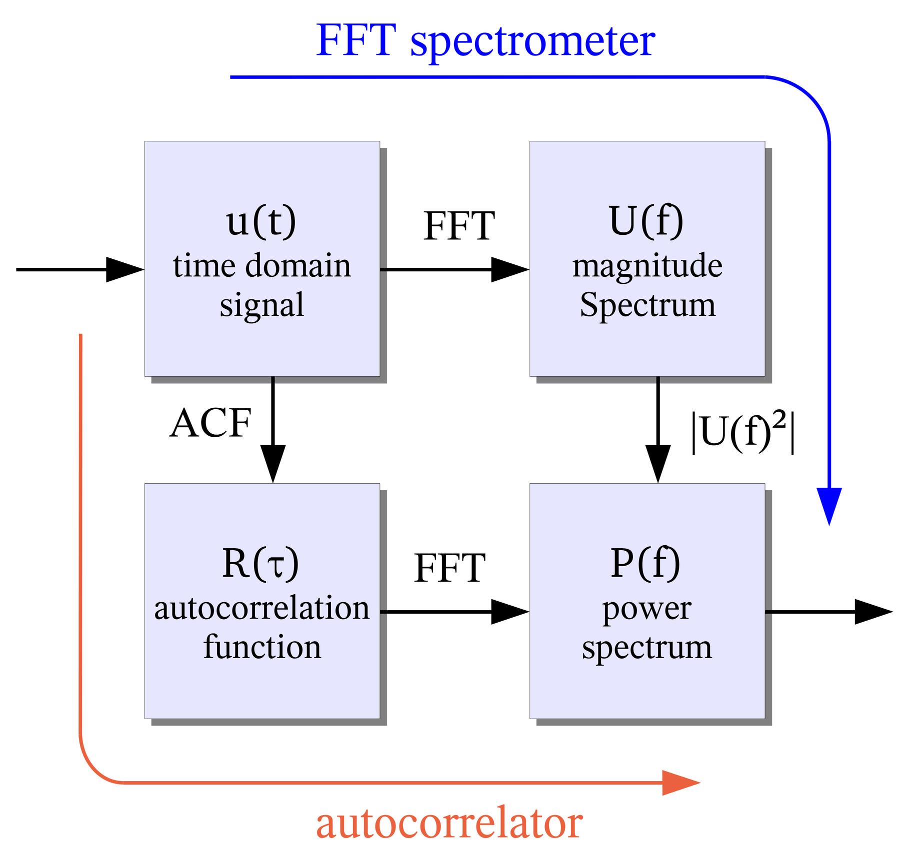

Fig 1 *"Wiener-Khinchin-Theorem": FFT spectrometer implement an alternative approach for obtaining the power spectrum of a given time signal.*

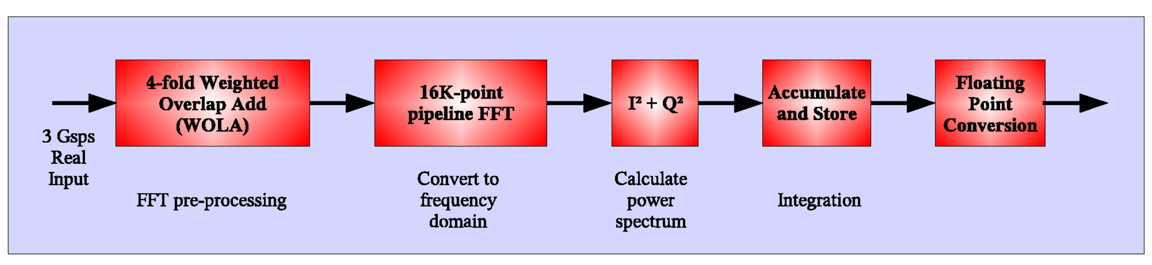

Fig 2 *Block diagram of the FPGA signal processing pipeline*

First-light of the new MPI FFT spectrometer board

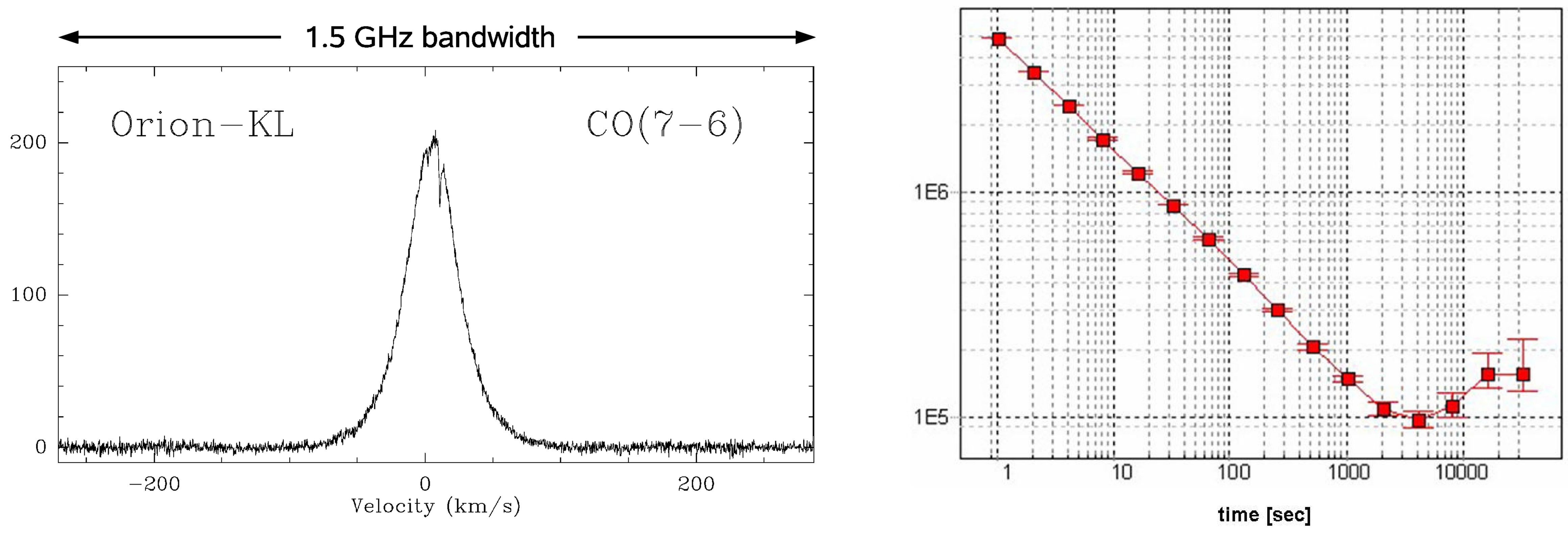

Fig 3 *First-light spectrum with our new 1.5 GHz wideband FFT spectrometer towards the hot core Orion-KL (24.10.07). The high-excitation CO(7-6) transition at 806 GHz was observed with the central pixel of the CHAMP+ array @ APEX. To the right, an Allan-Variance-Plot illustrates the superior stability of this FFTS. Data from a 0-1 GHz noise source were processed in 1 MHz bins. The spectroscopic variance between two 1 MHz broad channels, separated by 600 MHz within the band, was determined to be stable on a timescale of ~4000 s.*

The MPIfR 1.5 GHz Array FFT spectrometer (AFFTS) system

After the successful verification of the prototype, we launched the development of a most powerful backend array of 32 x 1.5 GHz boards, each with 8K channels. The unit will replace our correlator array MACS at the APEX, serving the current and next generation of heterodyne arrays.

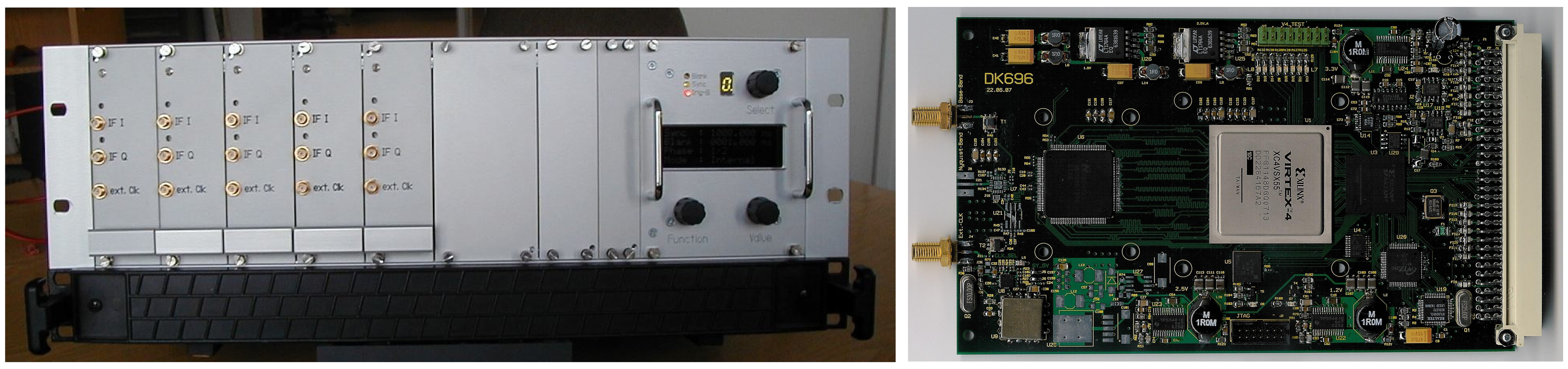

Fig 4 *Prototype of the MPIfR broad-band Array FFTS (AFFTS) equipped with 5 FFTS boards (right). The final AFFTS will consist of four crates with 8 FFTS boards each. A single board will provide 1.5 GHz bandwidth with 8K channels.*

A wideband high-resolution FFTS for GREAT/SOFIA

Motivated by the great success of these developments a wideband FFTS will be operated with GREAT on SOFIA, complementing the existing suite of backends. In view of the tremendous progress of both faster ADCs and more powerful FPGAs, we aim for a 2.5 GHz wide monolithic FFT spectrometer with adequate spectral resolution (few 100 kHz), to be operational in time for SOFIA's early science flights.

Advantages of the new MPI-FFTS

We summarize the striking advantages of this new generation of compact FFT spectrometers:

- FFTS offer high coherent bandwidth (today 1.5 GHz) with many thousand frequency channels, thus offering broadband observations with high spectral resolution without additional IF processing.
- They provide very high stability by exclusive digital signal processing (Allan variance stability plot).
- Field-operation has been proven to be very reliable, with calibration- and aging-free digital processing boards, which are swiftly re-programmable for special observation modes.
- Low space and power requirements – thus safe to use at high altitude (e.g. APEX at 5100-m) as well as on spacecrafts and satellites.
- Productions costs are low compared to traditional spectrometers through the use of only commercial parts.

References

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[2] Klein, B., Philipp, S.D., Krämer, I., Kasemann, C., Güsten, R., Menten, K.M., "The APEX Digital Fast Fourier Transform Spectrometer", 2006, A&A, 454, L29

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