High-resolution wide-band Fast Fourier Transform Spectrometer

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Abstract

We review the development of our digital broad-band Fast Fourier Transform Spectrometers: FFTS. In just a few years, FFTS back-ends – optimized for a wide range of radio astronomical applications – have become a new standard for heterodyne receivers, particularly in the mm and sub-mm wavelength range. They offer high instantaneous bandwidths with many thousands spectral channels on a small electronic board. Our FFT spectrometers make use of the latest version of commercially available analog-to-digital converters (ADC) and the most complex field programmable gate array (FPGA) chips available today. These state-of-the-art chips have made possible to build spectrometers with instantaneous bandwidths up to 2.5 GHz and 65536 (64k) spectral channels.

Our next FFTS development will be the design of a spectrometer with instantaneous bandwidth ≥4 GHz and up to 128k spectral channels, aiming at operational readiness in time for the commissioning of our upGREAT detector array for SOFIA and the LAsMA array receiver at APEX.

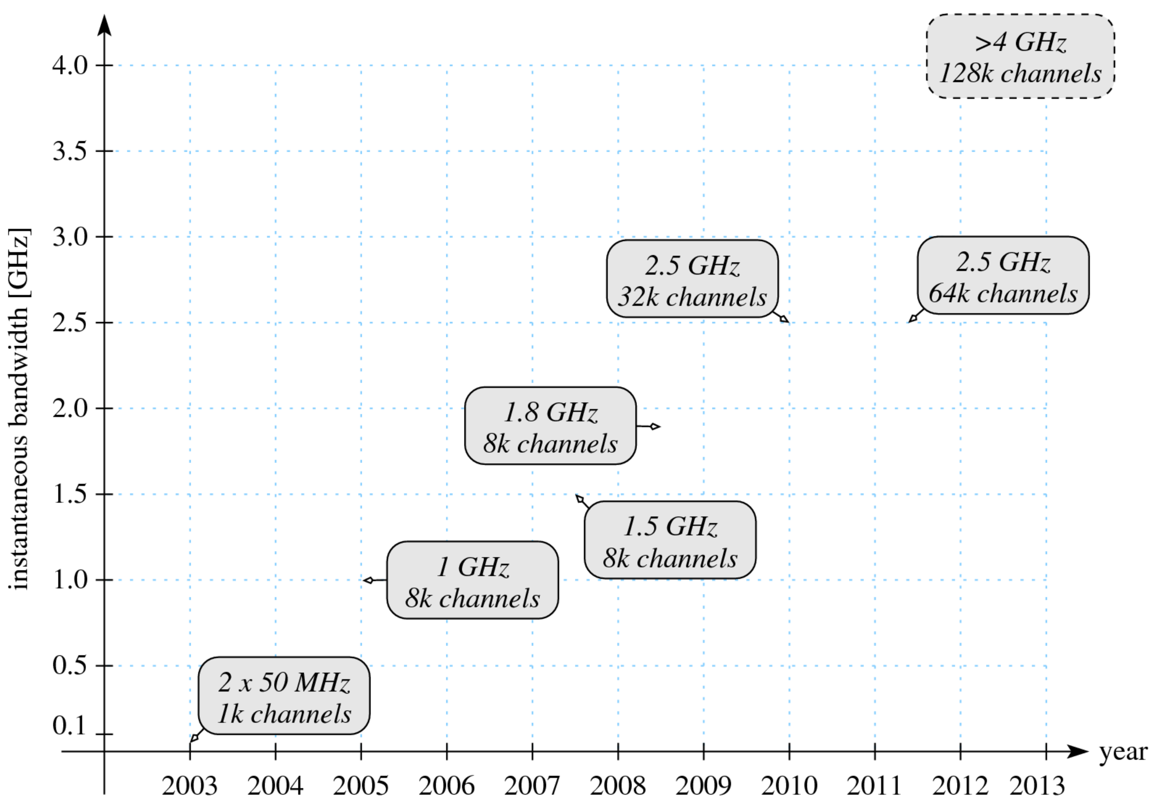


Fig 1 Overview of the FFTS developments at the Max-Planck-Institut für Radioastronomie. In the last 8 years it was possible to improve the instantaneous bandwidth by a factor of 50 while processing 64 times more spectral channels. The dashed box marks the design goals for our next generation FFTS.

Future Developments

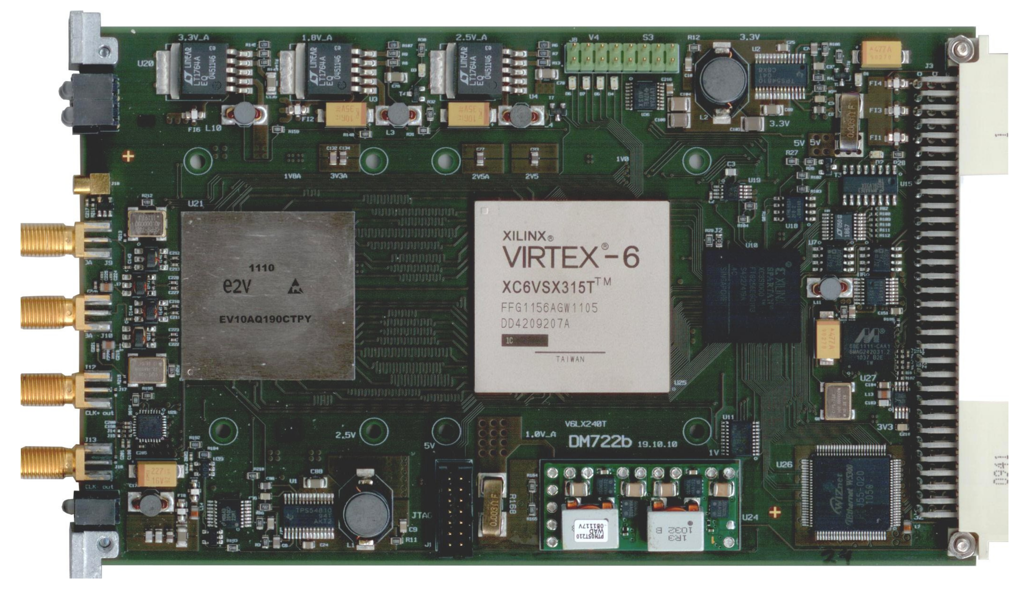
In current FFTS applications an IF processor is needed for down-mixing the receiver signals to baseband. However, the analog processors have many disadvantages, e.g. cost-intensive and not calibration- and aging-free. The notification of new ADCs with track-and-hold amplifiers, operating at GHz frequencies, will allow direct sampling of the IF of current and future receivers by bandpass-sampling techniques, with much reduced complexity and reduced costs.

Dual sideband (2SB) receivers are extensively used in mm/submm radio astronomy for line observations of complex astronomical signals to avoid spectral confusion. Today, excellent 2SB receivers obtain sideband rejection rations of 10 – 15 dB, insufficient for a number of astronomical observations.
Currently, we are working on a concept to replace the analog IF-hybrid by a corresponding digital signal processing on the FPGA together with a set of calibration vectors. For an accurate calibrated receiver we expect a sideband separating ratio of ~40 dB over the full bandwidth for 8-bit sampling.

AFFTS: The 32 × 1.5 GHz bandwidth Array-FFTS

Fig 2 The APEX wideband AFFTS consists of four FFTS-crates, each equipped with 8 FFTS boards and one FFTS-controller. The frequency resolution (equivalent noise band-width) for the standard configuration with 1.5 GHz band-width and 8192 spectral channels per board is 212 kHz, corresponding to 0,13 km/s at 500 GHz.

XFFTS: The 2.5 GHz eXtended bandwidth / 65536 channel FFTS



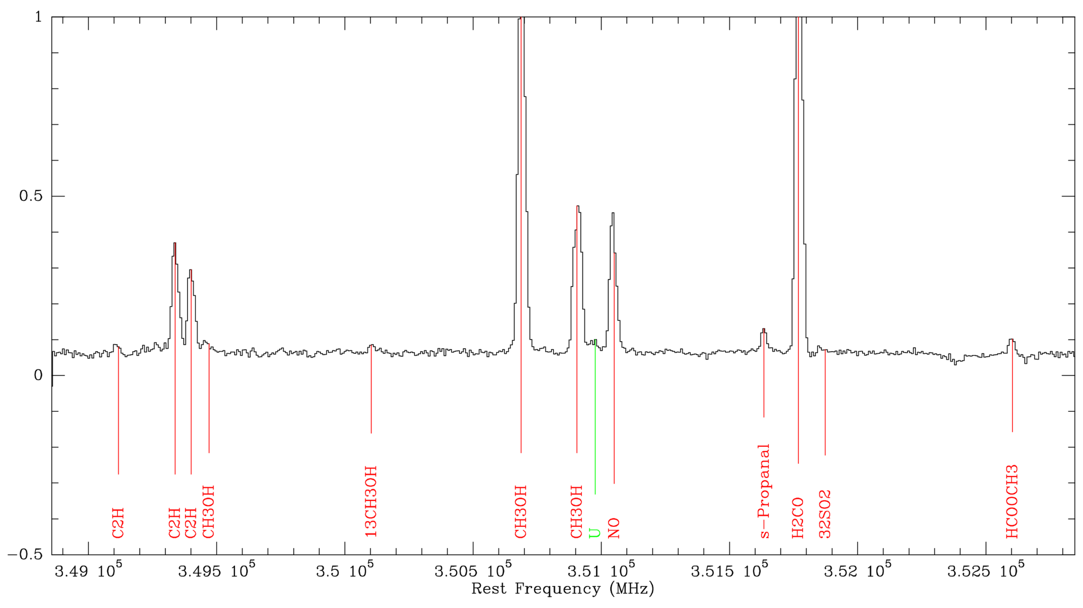


Fig 3 Left: XFFTS board that uses E2V's fastest 4 x 1.25 GS/s 10-bit ADC and the high-performance Xilinx Virtex-6 SX315T FPGA. By applying time interleave techniques, the four 1.25 GS/s ADCs can be combined into one 5 GS/s converter. The XFFTS allows analyzing an instantaneous bandwidth of 2.5 GHz with up to 65536 spectral channels. Right: Two 2.5 GHz XFFTS boards combined, with 500 MHz overlap, to create a 4 GHz wide spectrometer. The sample spectrum, part of the Galactic Center line survey, shows the upper sideband of the sideband separating APEX / Flash+ receiver.

In development: UWFFTS – The Ultra-Wide-band FFTS

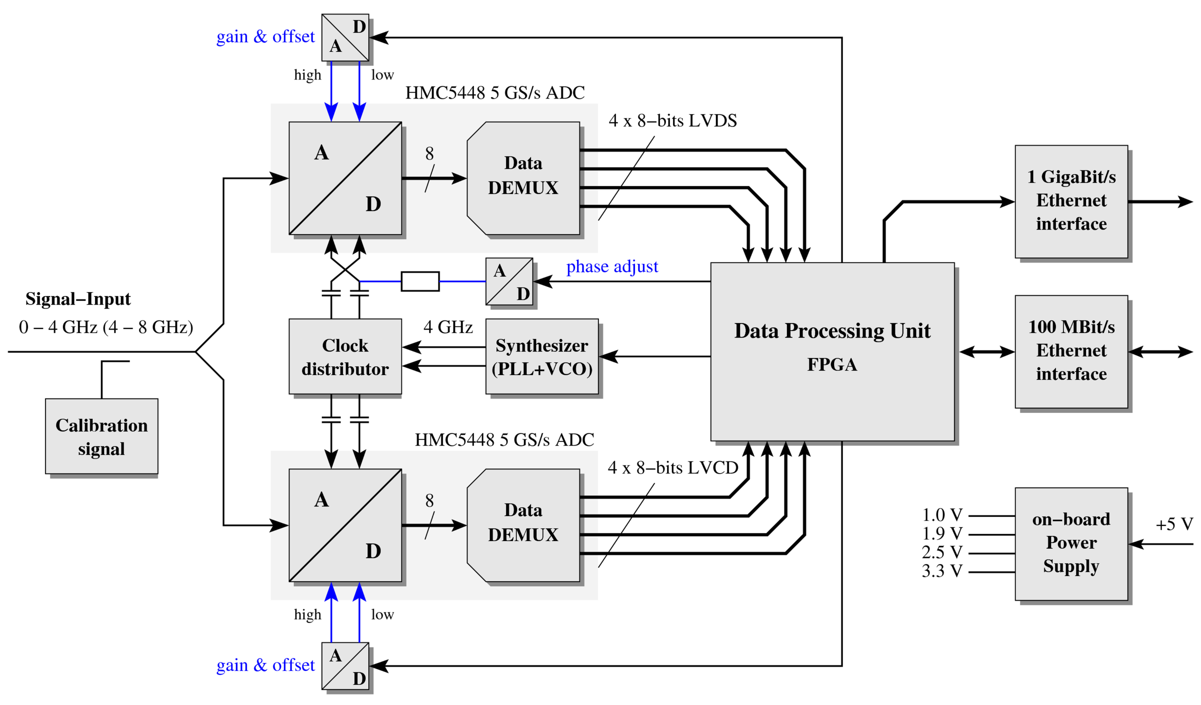


Fig 4 Block diagram of the Ultra-Wide-band FFTS. The availability of a novel monolithic high-speed 8-bit ADC from Hittite with an analog input bandwidth of up to ~8 GHz allows direct sampling of a receiver IF from 4 to 8 GHz by external ADC interleaving. The enormously increased computing power of a new generation of Xilinx Virtex-7 FPGAs makes it likely to transform the 4 GHz bandwidth in 128k spectral channels. The UWFFTS will reduce both, the complexity and the cost of future IF signal processors particular for large receiver arrays, e.g. LAsMA.

New concept: DSSFFTS – The Digital Sideband Separating FFTS

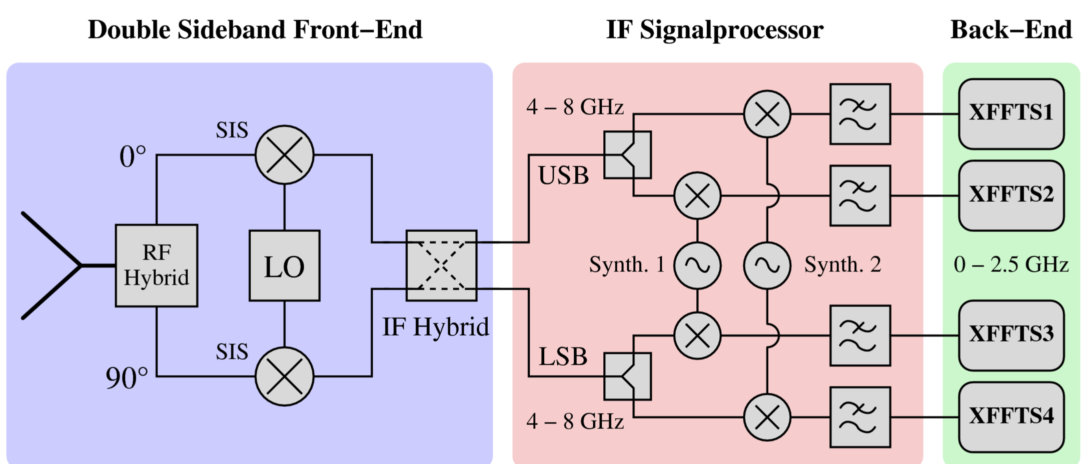


Fig 5a Block diagram of a conventional dual sideband (2SB) receiver. Known problems:
- *Amplitude and phase imbalances limit the sideband separation ratio to 10 – 15 dB for wide bandwidth receivers.*
- *An analog IF signal processor can become very complex, expensive and unstable.*

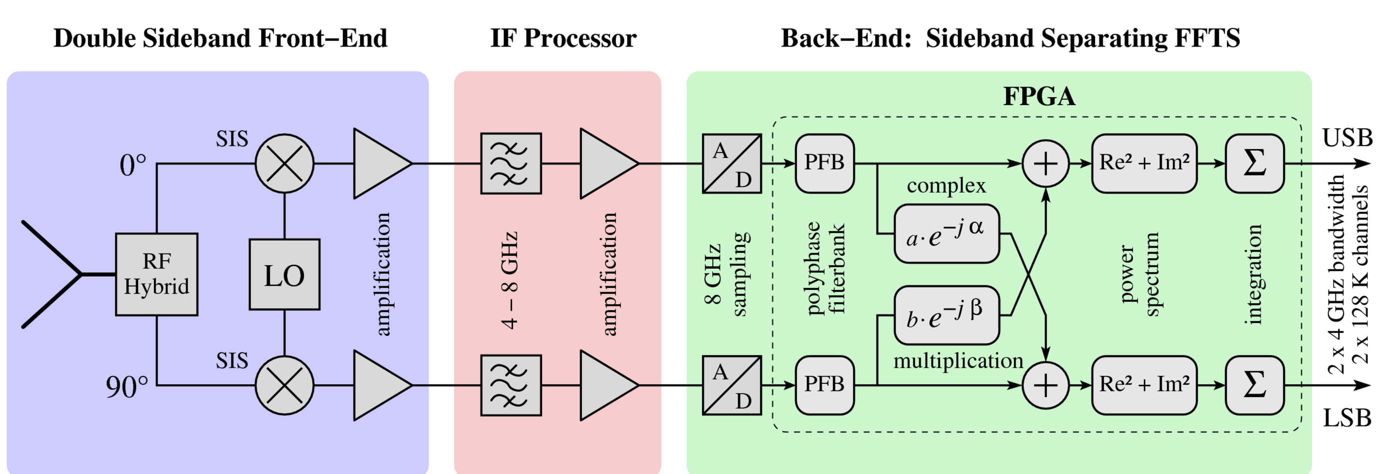


Fig 5b Block diagram of a novel 2SB receiver concept. The original front-end IF-hybrid is shifted to the digital domain (FFTS). A complex multiplication after the polyphase filter bank (PFB) by a calibration vector compensates amplitude and phase imbalances of the analog front-end components for each spectral channel. This concept allows to design 2SB receivers with unprecedented sideband rejection and less complexity at lower cost.