Fast Fourier Transform Spectrometer (FFTS)

Past, Present and Future

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- Germany -
Improvement in bandwidth by a factor of 50 over 7 years or 350 MHz per year!
FFTS :: 1.5 GHz bandwidth Board

- Instantaneous bandwidth: 0.1 – 1.8 GHz
- Spectral resolution @ 1.5 GHz: 212 kHz
- Calibration- and aging free digital processing
Unlike the conventional windowed-FFT processing, a more efficient polyphase pre-processing algorithm has been developed with significantly reduced frequency scallop, less noise bandwidth expansion, and faster sidelobe fall-off.

Equivalent noise bandwidth = 1.16 x frequency spacing
The Equivalent Noise Bandwidth (ENBW) is the width of a fictitious rectangular filter such that the power in that rectangular band is equal to the (integrated) response of the actual filter.

Today, implemented FFTS board / FPGA configurations are:

- 1 x 1.5 GHz bandwidth, 1 x 8192 spectral channels, ENBW: 212 kHz (default core)
- 1 x 1.8 GHz bandwidth, 1 x 8192 spectral channels, ENBW: 255 kHz
- 1 x 750 MHz bandwidth, 1 x 16382 spectral channels, ENBW: 53 kHz
- 1 x 500 MHz bandwidth, 1 x 16384 spectral channels, ENBW: 35 kHz
- 1 x 100 MHz bandwidth, 1 x 16384 spectral channels, ENBW: 7 kHz
- 1 x 50 MHz bandwidth, 1 x 16384 spectral channels, ENBW: \(~ 4 \text{ kHz}\)
The spectroscopic Allan variance between two 1 MHz broad channels, separated by 800 MHz within the band, was determined to be stable on a timescale of ~4000 s.
AFFTS :: Array-FFTS for APEX

Bandwidth: 32 x 1.5 GHz = 48 GHz (option 58 GHz)
Spec. channels: 32 x 8k = 256k channels @ 212 kHz
The superior performance, high sensitivity and reliability of MPIfR FFT spectrometers has now been demonstrated at many telescopes world-wide.

Spectrum towards Orion-KL. The high-excitation CO(7-6) transition at 806 GHz was observed with the central pixel of the CHAMP+ array.

Further details:
- http://www.mpifr-bonn.mpg.de/staff/bklein
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For further information about the MPIfR FFT spectrometer, future developments and applications, please contact Bernd Klein (bklein@mpifr.de) or Rolf Güsten (rguesten@mpifr.de) at the Max-Planck-Institut für Radioastronomie in Bonn, Germany.

Distribution:
http://www.radiometer-physics.de
Applications:

- **Spectroscopy**: 16 x 100 - 500 MHz bandwidth, 8192 and 16384 channels
- **Pulsar Search**: 16 x 250 MHz bandwidth, 512 channels, 32/64µs dumping
EFFTS :: The analyzer board

Board modifications:

- Dual input ADC :: National ADC08D1500, 2 x 750 MHz bandwidth
- GigaBit Ethernet :: Marvell 88E1111, UDP: 85 MBytes/sec cont.
EFFTS :: pulsar signal processing

Performance:

- **FPGA processing** :: 250 MHz bandwidth & 8-tab polyphase filterbank with 512 channels, ENBW: 515 kHz
- **Dump time [µs]** :: 32, 64 or 128, 16 x 512 channels (32-bit float) 1k Bytes tail (dump counter, GPS/IRIG-B time,...)
- **Data rate @ 32µs** :: ~64 MBytes/sec
EFFTS :: The Effelsberg FFTS
PSR J1745+10 - first MSP discovery in Effelsberg, P = 2.65 ms
LAB-FFTS:

2 x 1.8 GHz bandwidth, 8192 spectral channels, ENBW: 255 kHz
4 x 750 MHz bandwidth, 16384 spectral channels, ENBW: 53 kHz
E2V 5 GS/s 10-bit ADC, XILINX Virtex-6 LX240T
[ 40 nm, 1.0 volt core voltage, >240’000 logic cells, 768 DSP48 slices ]
XFFTS :: ADC interleaving

ADC: e2v 10-Bit, 4 x 1.25 GS/s
XFFTS :: ADC interleaving

Fin = 470 & 471 MHz, SFDR (Signal/IM3) = 53.1 dB
ADC: e2v 10-Bit, 4 x 1.25 GS/s
XFFTS: 2.5 GHz bandwidth / 10-bit / 32768 channels (ENBW 88.5 kHz)

Test line: 1.8 GHz / -60 dBm

2.5 GHz instantaneous bandwidth
XFFTS @ APEX :: IF-Processor

**XIF:** 2 x 4 GHz @ 6 GHz center frequency  ⇒  4 x 2.5 GHz (XFFTS)

Installation & Commissioning: June 2010
**XFFTS @ APEX**

**XFFTS**: 4 x 2.5 GHz, 4 x 32768 spectral channels, ENBW: 88,5 kHz

*Installation & Commissioning: June 2010*
SGRA – Line Survey

4 GHz bandwidth

Rest Frequency (MHz)
8 GHz of bandwidth in one setup

**lower sideband**

![Graph showing lower sideband](image)

**upper sideband**

![Graph showing upper sideband](image)

12 GHz spacing

**Flash345**: updated receiver with IRAM 2SB SIS mixer
New ADCs: e.g., ADC30 from MICRAM
- 30 GS/s sampling, 15 GHz Nyquist bandwidth
- 6 bit resolution, effective bits (ENOB): > 4.5 @ 14 GHz
- > 20 GHz analog bandwidth, allows direct IF sampling
- But – is this highly interleaved ADC good enough for Radioastronomy ??? We will see…

ADC30 Module
FFT-Spectrometer :: An Outlook

**XFFTS2:** support for 4 x 10 GBit/s Ethernet

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UniBoard

ROACH1/2

PC-Clusters

GPU-Clusters
Advantages of our new generation of compact FFT spectrometers:

- FFTS offer high instantaneous bandwidth up to 2.5 GHz with many thousands frequency channels, thus offering wideband observations with high spectral resolution without the complexity of the IF processing in a hybrid configuration.

- They provide very high stability by exclusive digital signal processing. Allan stability times of > 1000 seconds have been demonstrated routinely.

- Our optimized polyphase FFT signal processing pipeline provides a nearly loss-free time to frequency transformation with significant reduced frequency scallop, less noise bandwidth expansion, and faster side lobe fall-off.

- Field-operations of our FFTS over the last 4 years have proven to be very reliable, with calibration- and aging-free digital processing boards, which are swiftly re-configurable by Ethernet 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 (Sofia) and future satellites (Millimetron?).

- Production cost are low compared to traditional spectrometers through use of only commercial components.