Max-Planck-Institut
für Radioastronomie

DIGITALLABOR
01001010

High-resolution wide-band spectrometers for Large Heterodyne Arrays:

Fast Fourier Transform Spectrometer (FFTS)

Bernd Klein

Max-Planck-Institut für Radioastronomie, Bonn
University of Applied Sciences Bonn-Rhein-Sieg
- Germany -

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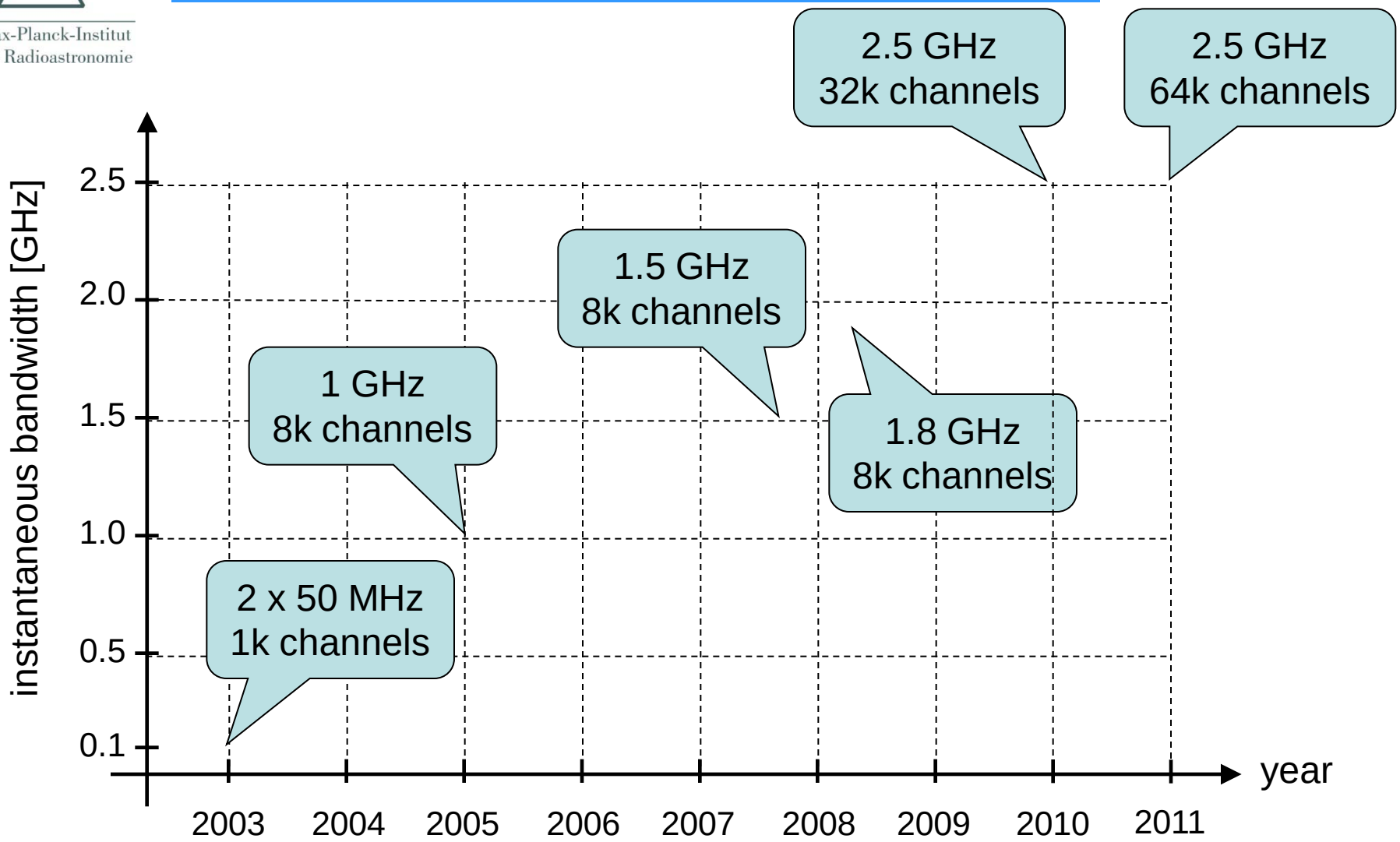
FFTS :: *A short "history"*



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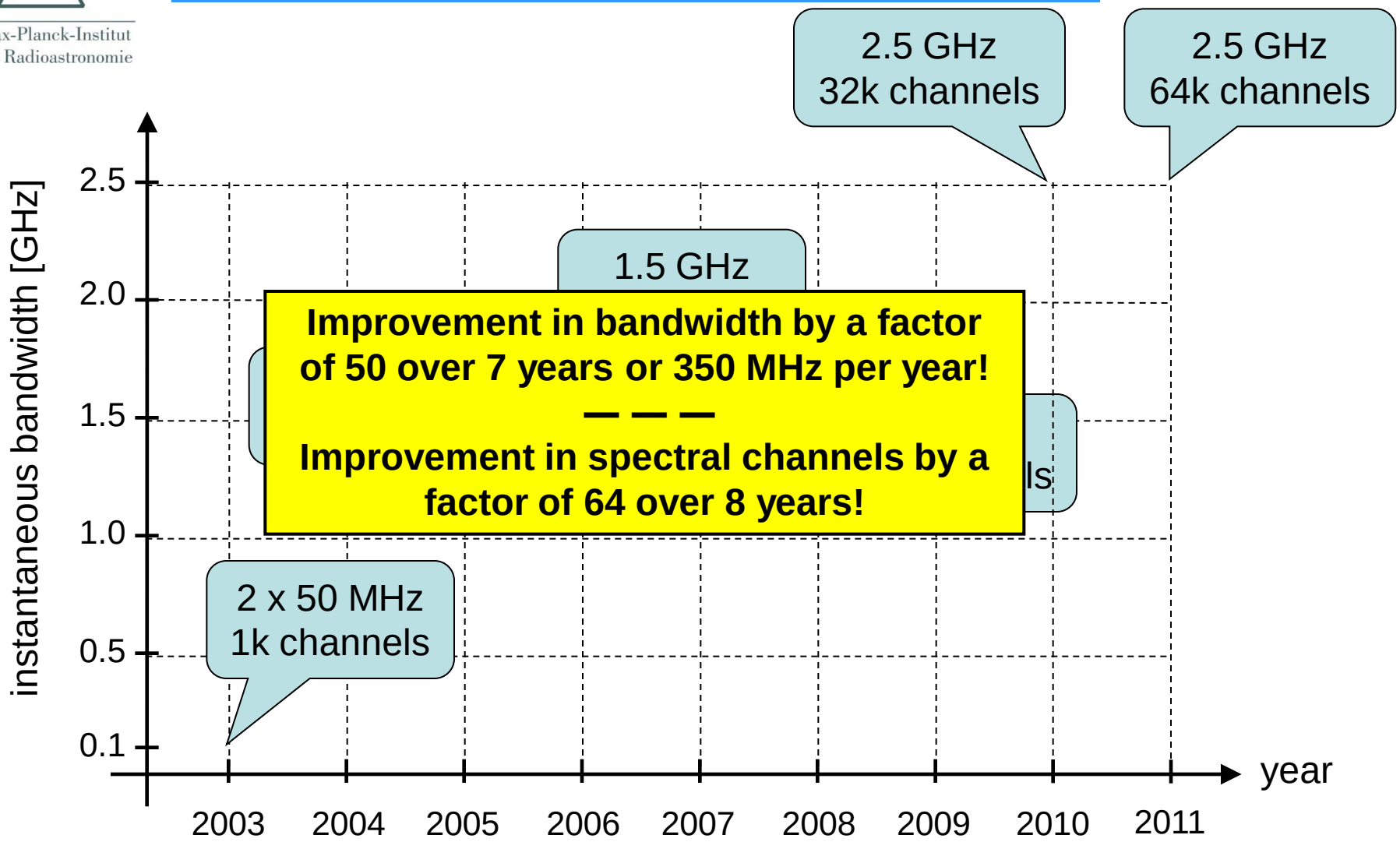

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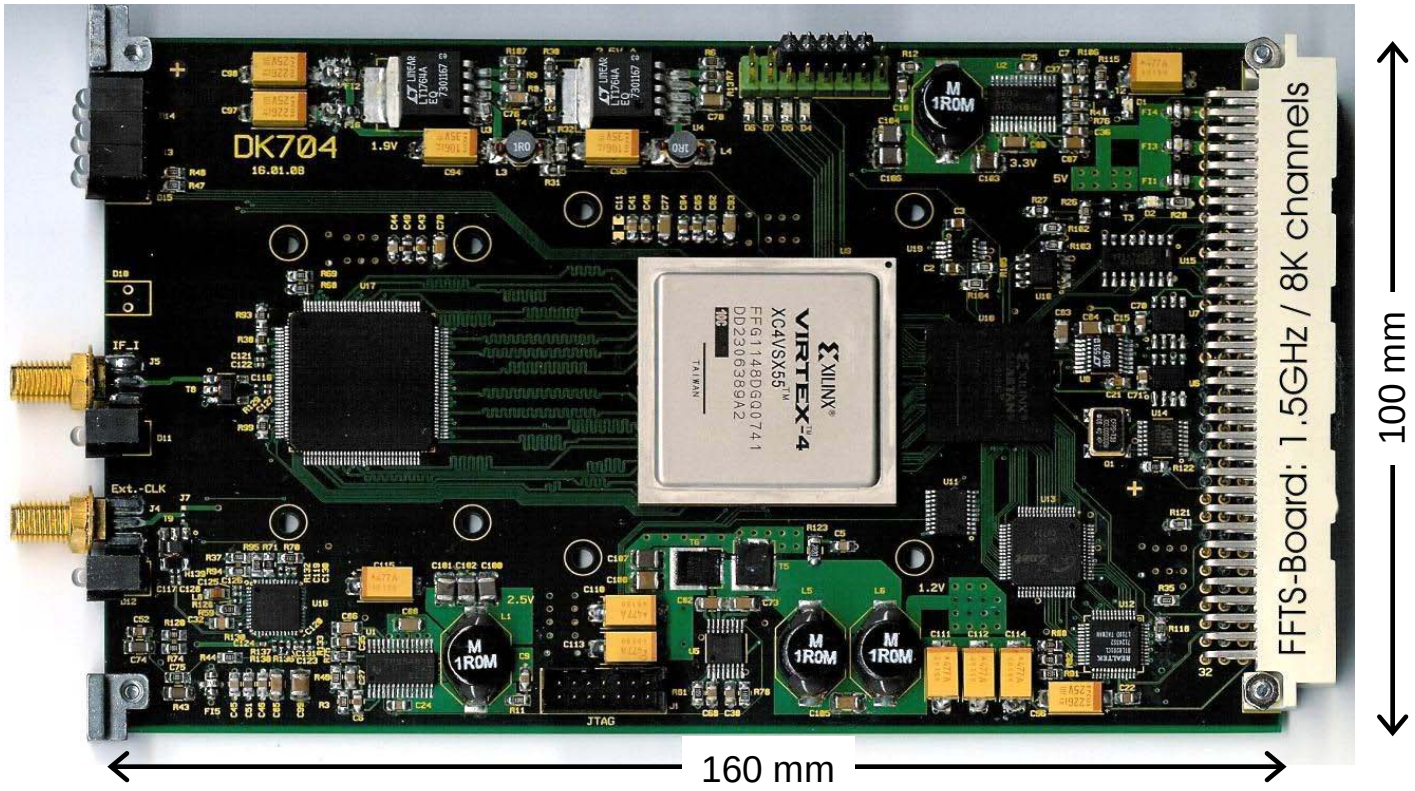
FFTS :: *1.5 GHz bandwidth Board*



- Instantaneous bandwidth: 0.1 – 1.5 GHz
- Spectral resolution @ 1.5 GHz: 212 kHz
- Calibration- and aging free digital processing

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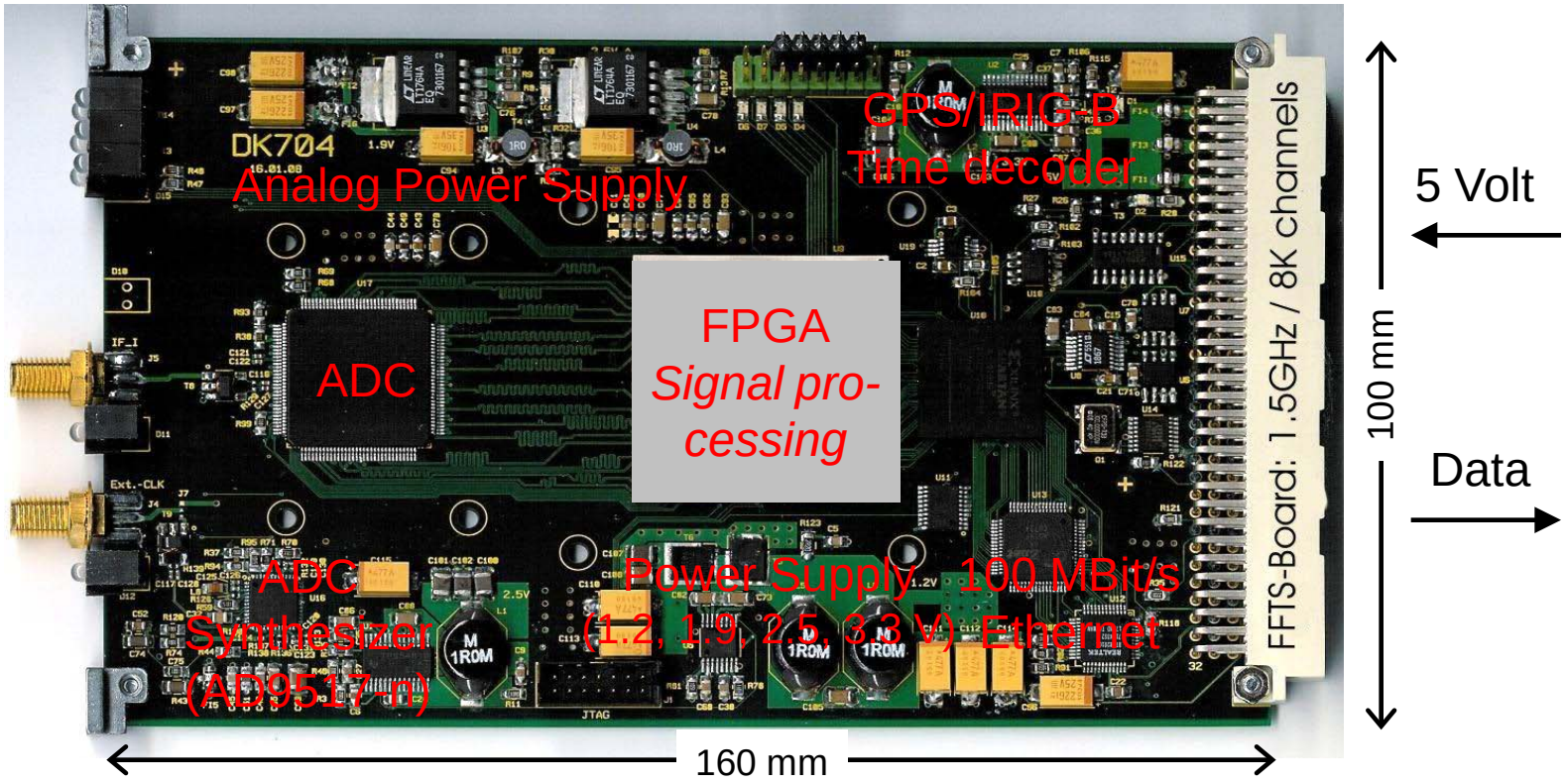
FFTS :: *1.5 GHz bandwidth Board*



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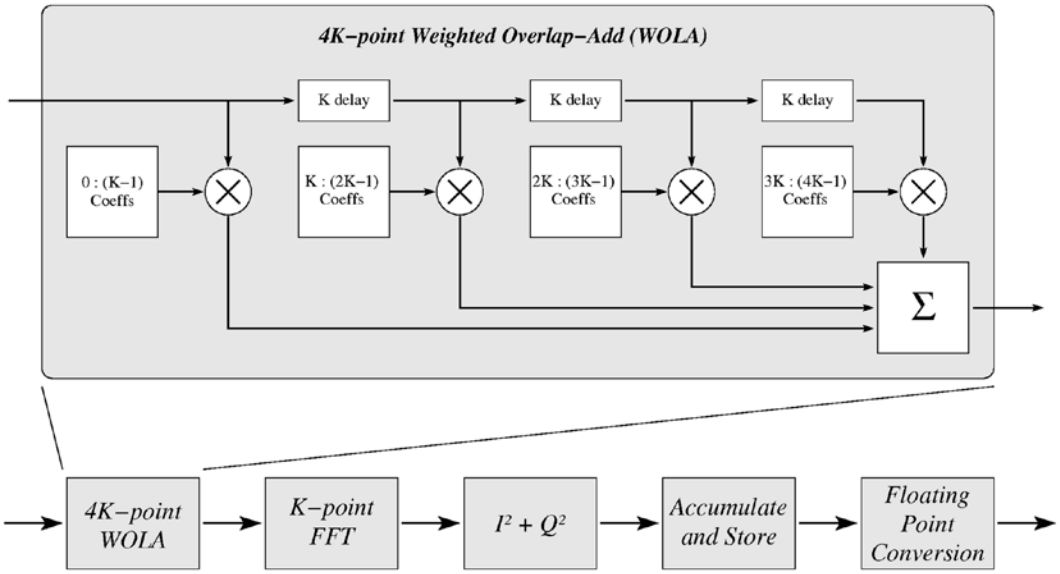
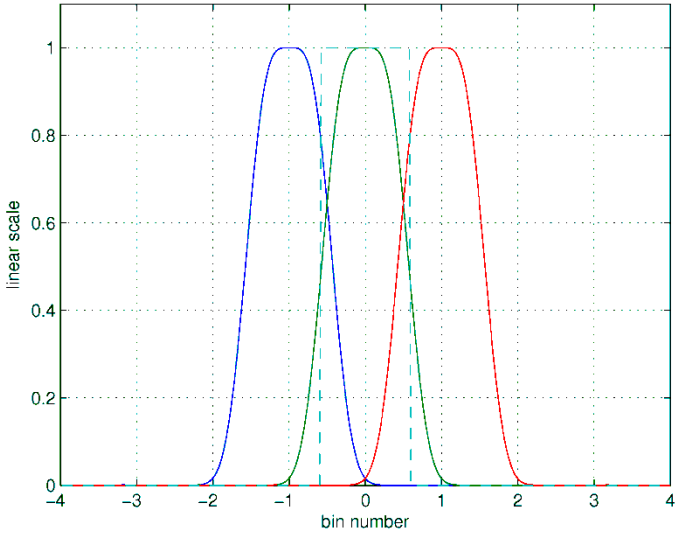
FFTS :: *Signal Processing*

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.





Frequency response of the optimized FFT signal processing pipeline

Equivalent noise bandwidth = 1.16 x frequency spacing

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FFTS :: *FPGA configurations*

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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 kHz

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.

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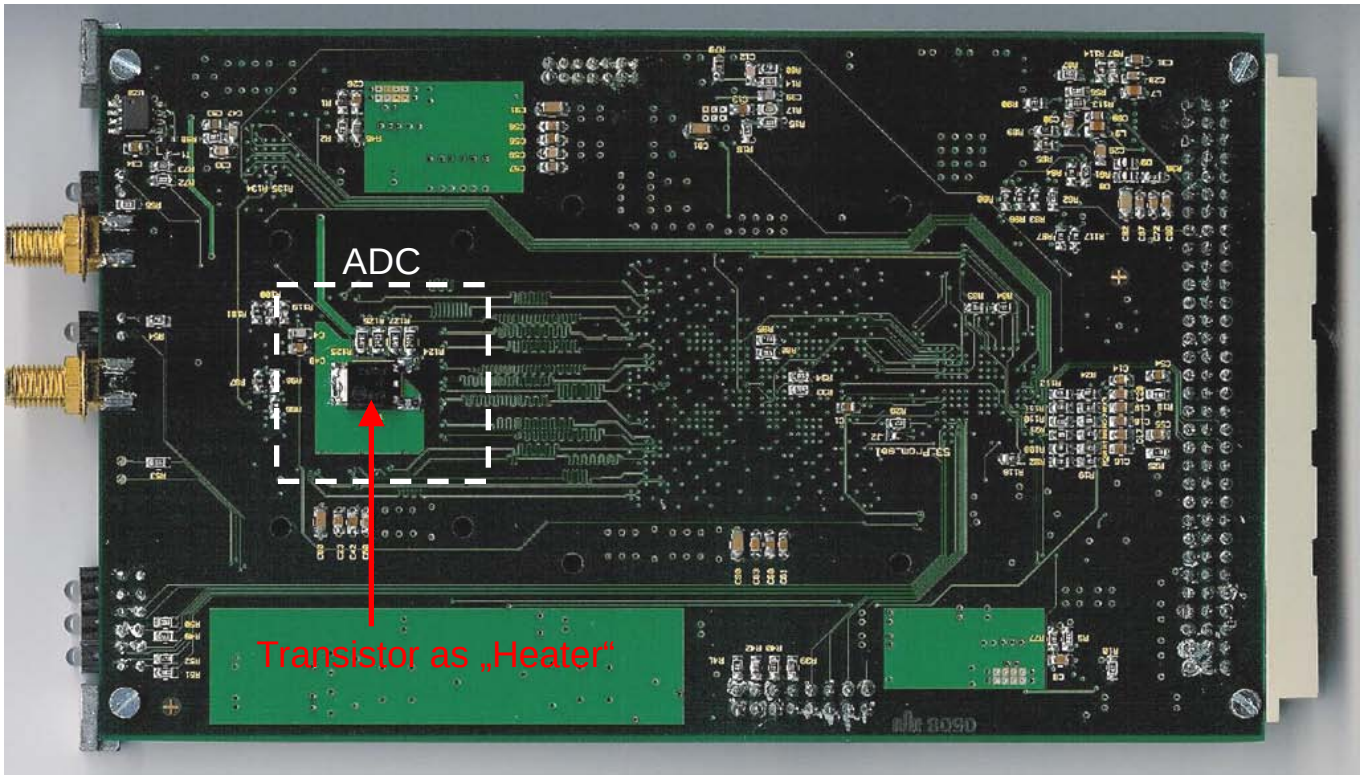
FFTS :: *Stability*



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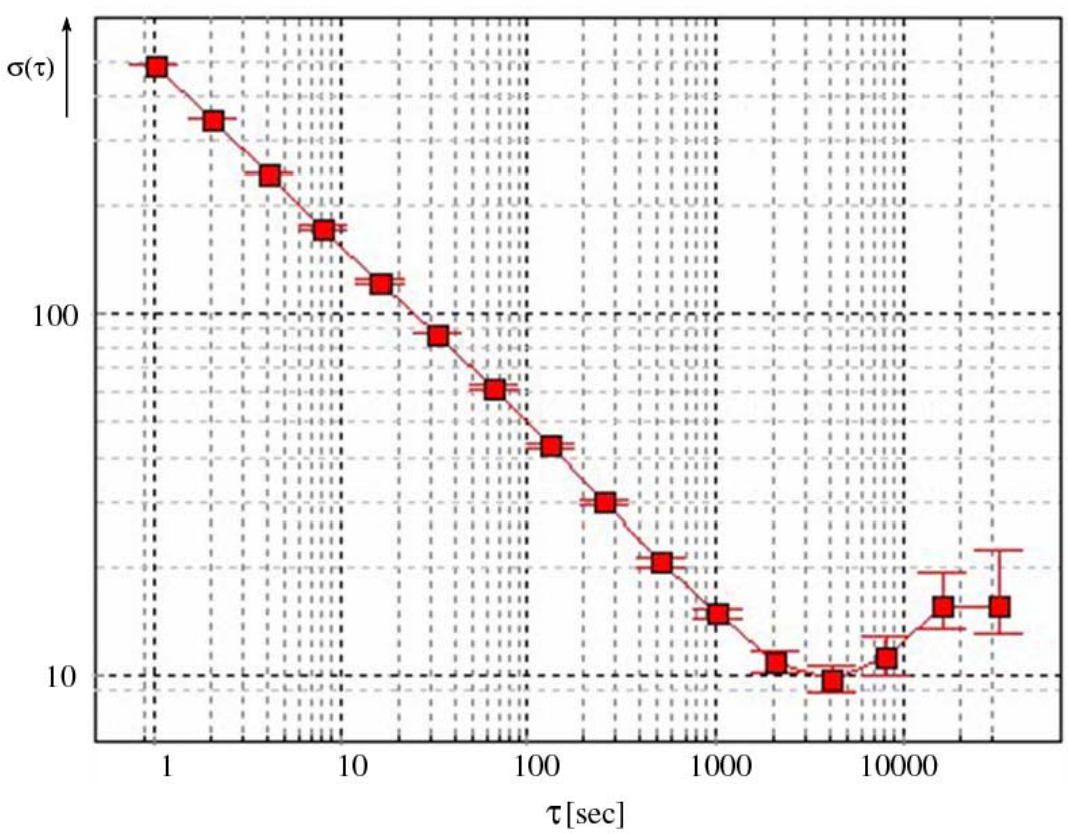
FFTS :: *Stability*



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.

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AFFTS :: *Array-FFTS for APEX*

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Atacama Pathfinder EXperiment
APEX

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AFFTS :: *Array-FFTS for APEX*

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Atacama Pathfinder EXperiment
APEX

Bandwidth: 32 x 1.5 GHz = 48 GHz (option 58 GHz)
Spec. channels: 32 x 8k = 256k channels @ 212 kHz

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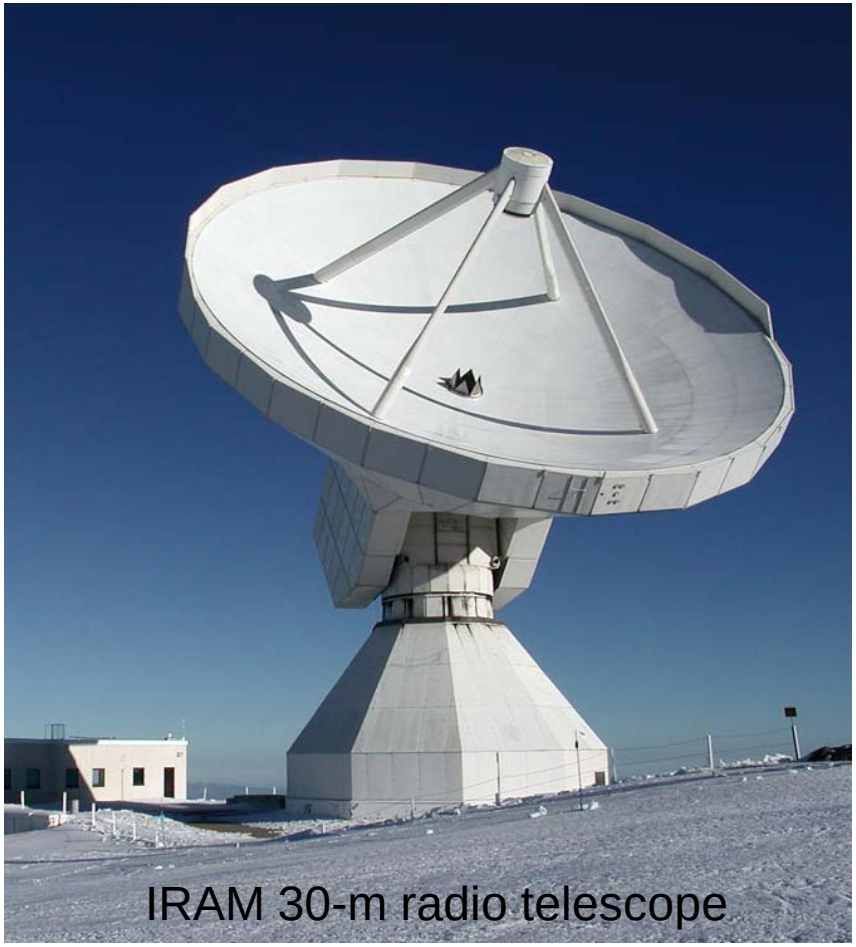
AFFTS @ IRAM 30-m

The new 32 GHz AFFTS at the 30-m telescope works in two modes:
50 and 200 kHz spectral resolution. – Commissioning: July 2011



IRAM 30-m radio telescope

Picture provided by C. Kramer (IRAM)

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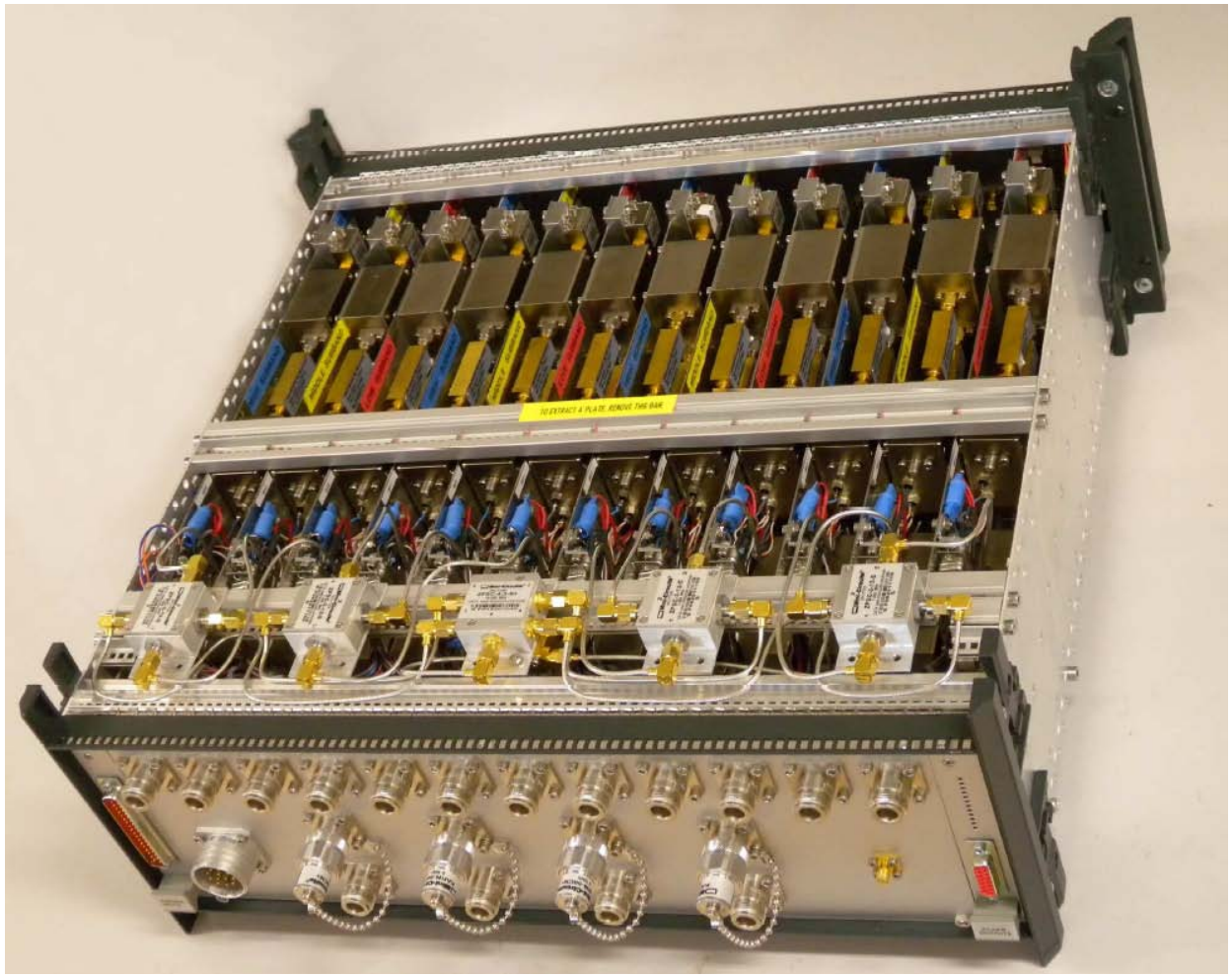
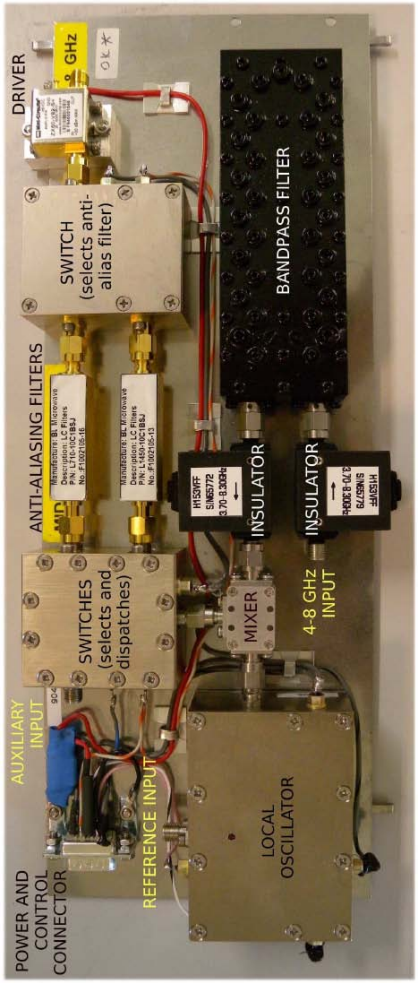
AFFTS @ IRAM 30-m

IRAM IF processor (spectrum slicer) for the Array-FFT-spectrometer.





Picture provided by C. Kramer (IRAM)

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AFFTS @ IRAM 30-m

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Frequency survey of NGC7023 covering 86 to 116 GHz at 50 kHz resolution.
The resulting spectrum consists of 740.149 spectral channels.

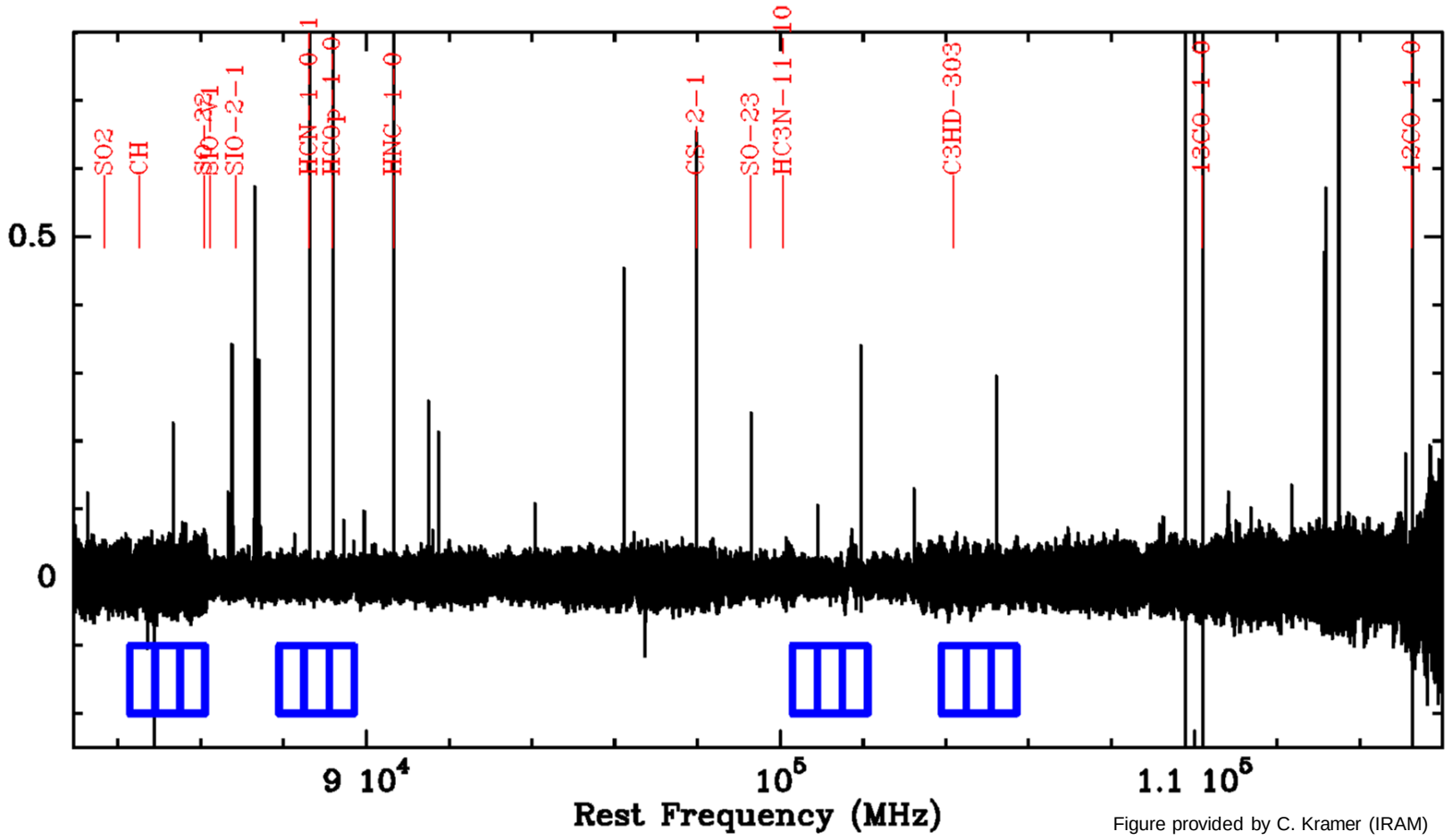

Figure provided by C. Kramer (IRAM)

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AFFTS @ IRAM 30-m

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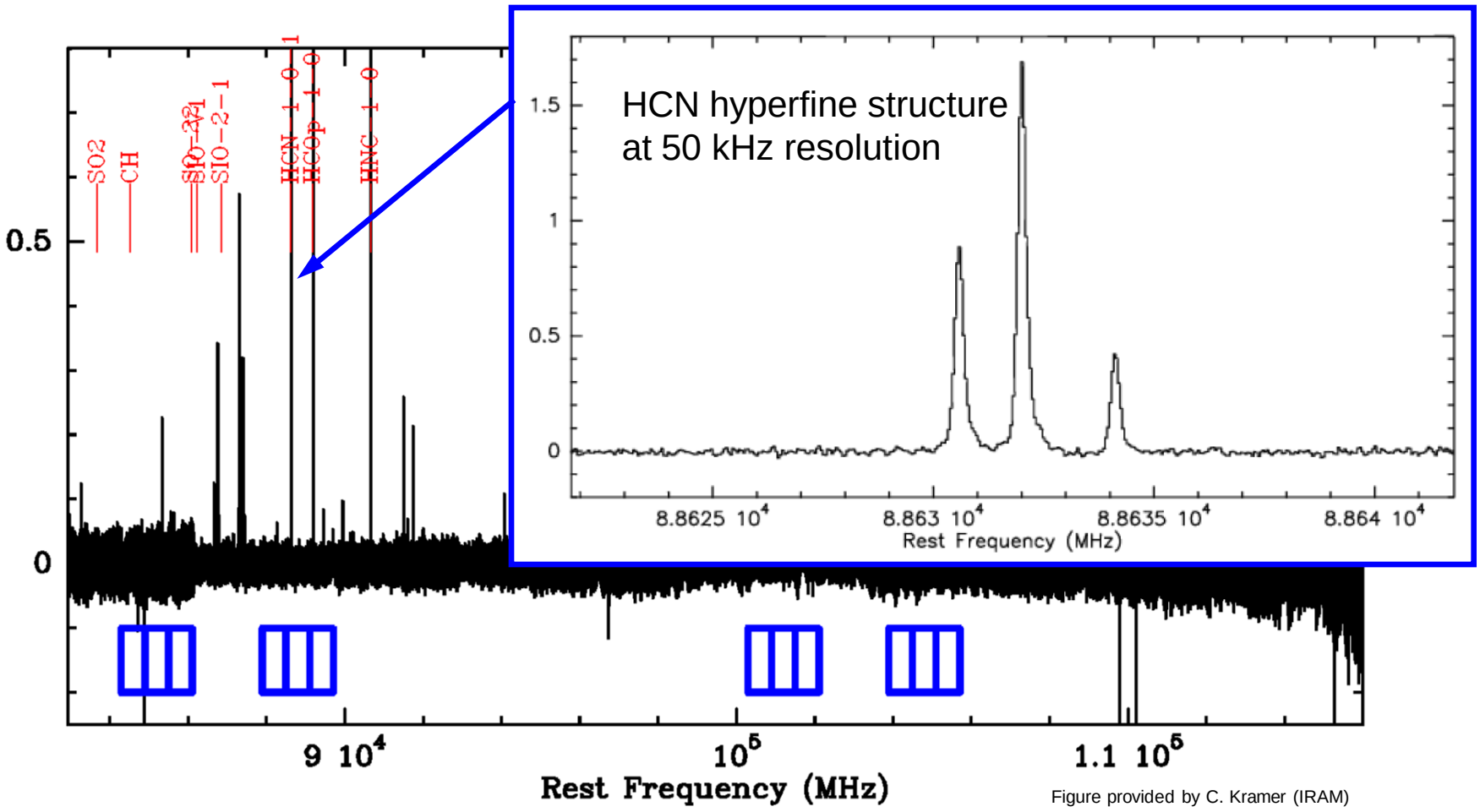

Figure provided by C. Kramer (IRAM)

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EFFTS :: *The Effelsberg FFTS*

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für Radioastronomie

EFFTS :: *The Effelsberg FFTS*

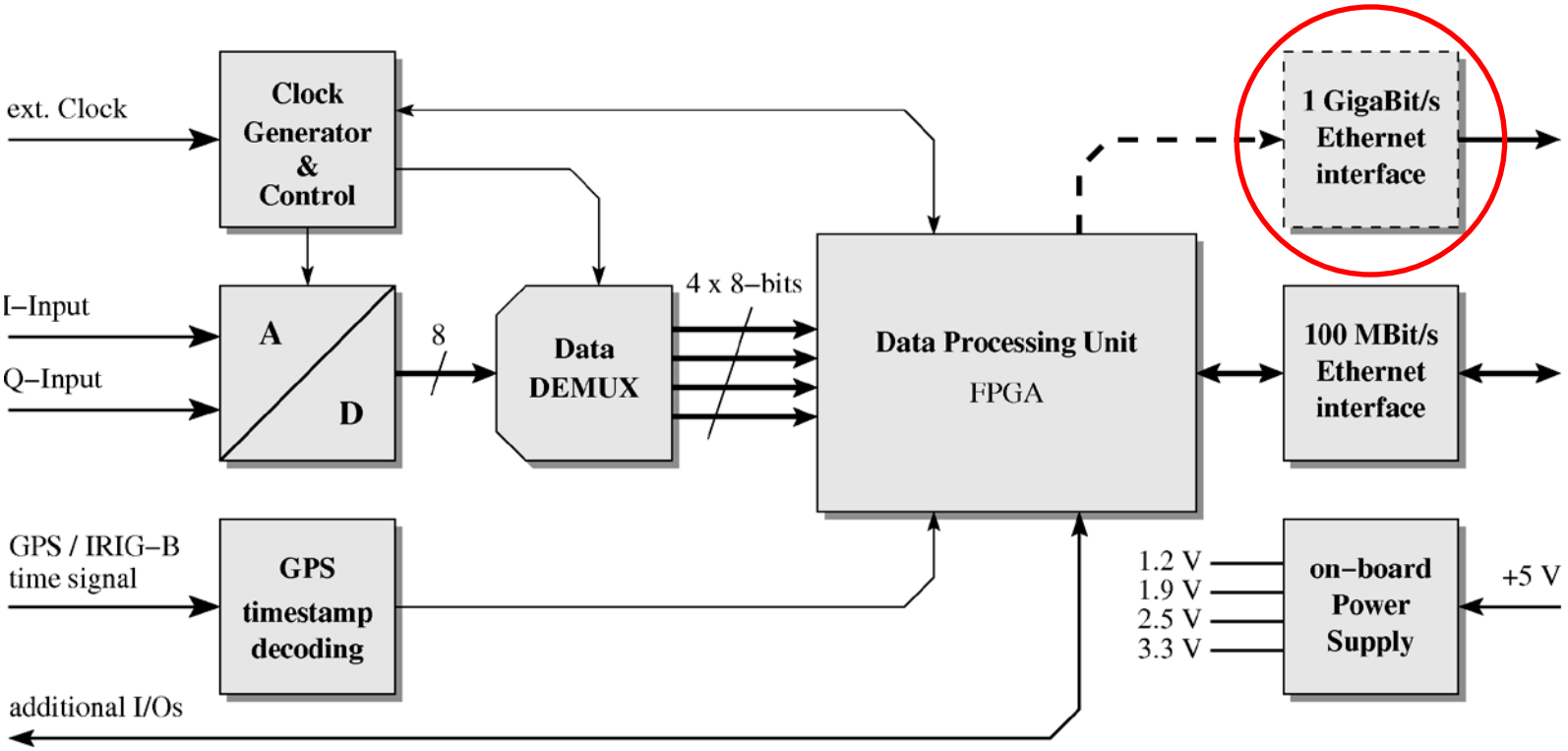
DIGITALLABOR

Norbert Tacken

EFFTS :: *The Effelsberg FFTS*

Applications:

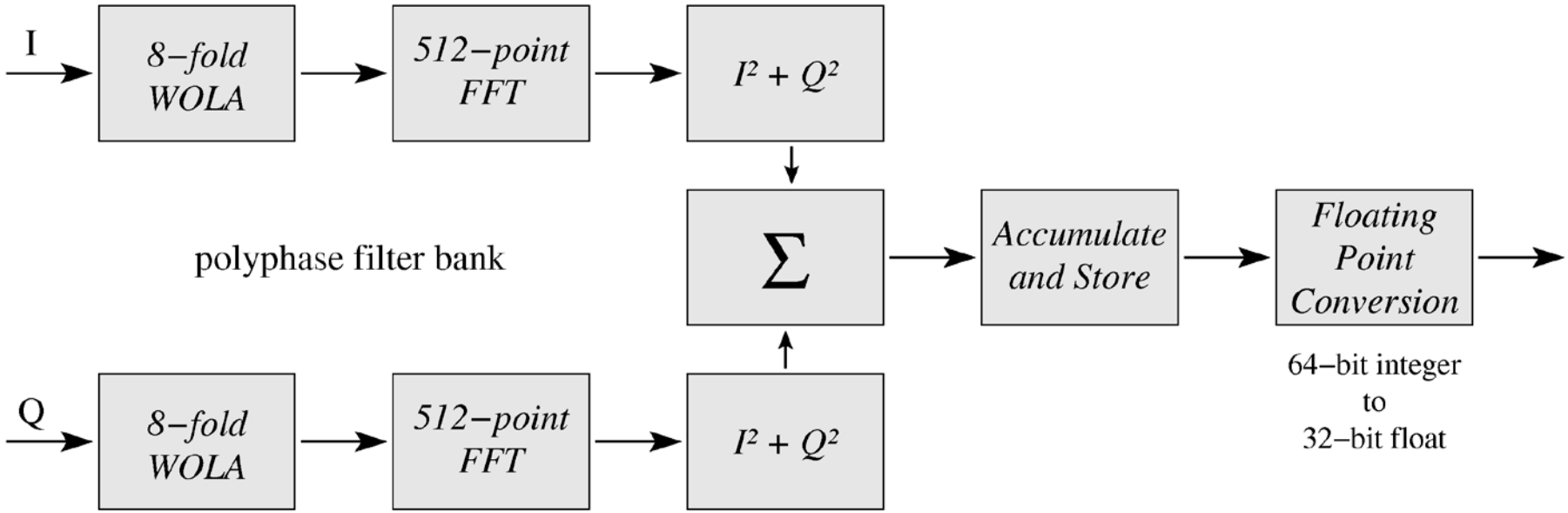
- Spectroscopy :: 16 x 100 - 500 MHz bandwidth, 8192 and 16384 channels
- Pulsar Search :: 16 x 250 MHz bandwidth, 512 channels, 32/64µs dumping



EFFTS :: *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



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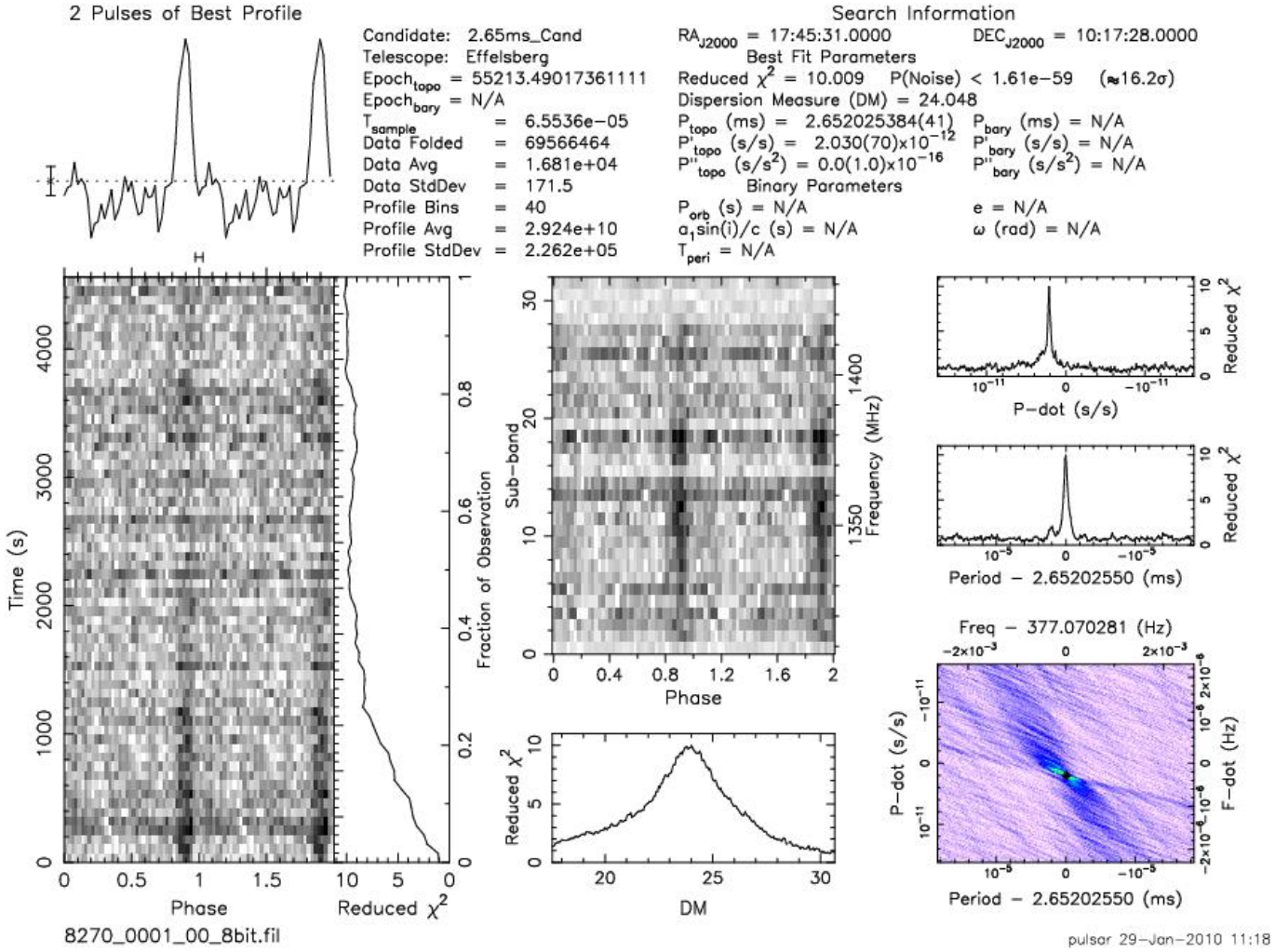
EFFTS :: *Pulsar discovery*

PSR J1745+10 - first MSP discovery in Effelsberg, P = 2,65 ms



Microwave Kinetic Inductance Detector
— Readout concept —

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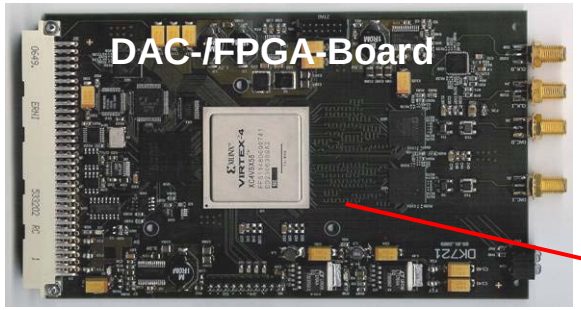
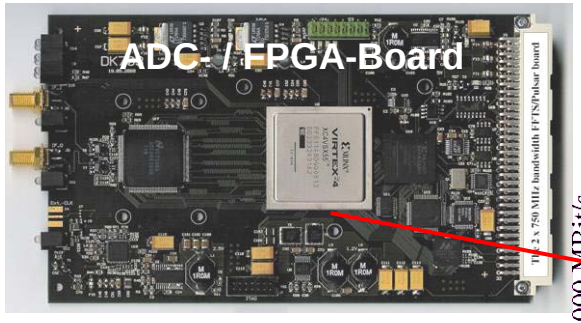
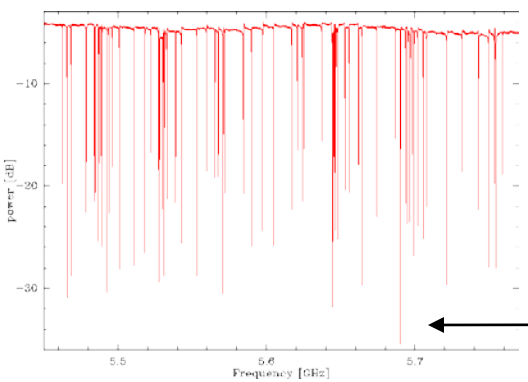






reference frequency

(e.g. 10 MHz)

IF–Synthesizer

DAC–/FPGA–Board
(programmable tone generator)

Baseband

SSB upconverter

synchonisation

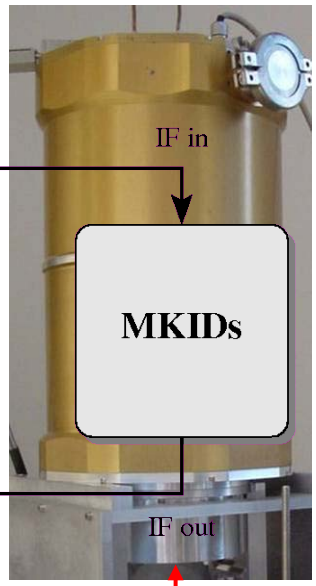
ADC–/FPGA–Board
(synchron time integration)

SSB downconverter

Ethernet 100/1000 MBit/s

Linux–PC
- *KIDs readout control*
- *complex FFT*
- *data processing & recording*

Cryostat



IF-system

Signal

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FFTS :: *The Laboratory version*

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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

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XFFTS :: *The Sofia spectrometer*

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GREAT

XFFTS: 2.5 GHz bandwidth / 32768 channels (ENBW 88.5 kHz)

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XFFTS :: *The Sofia spectrometer*

DIGITALLABOR

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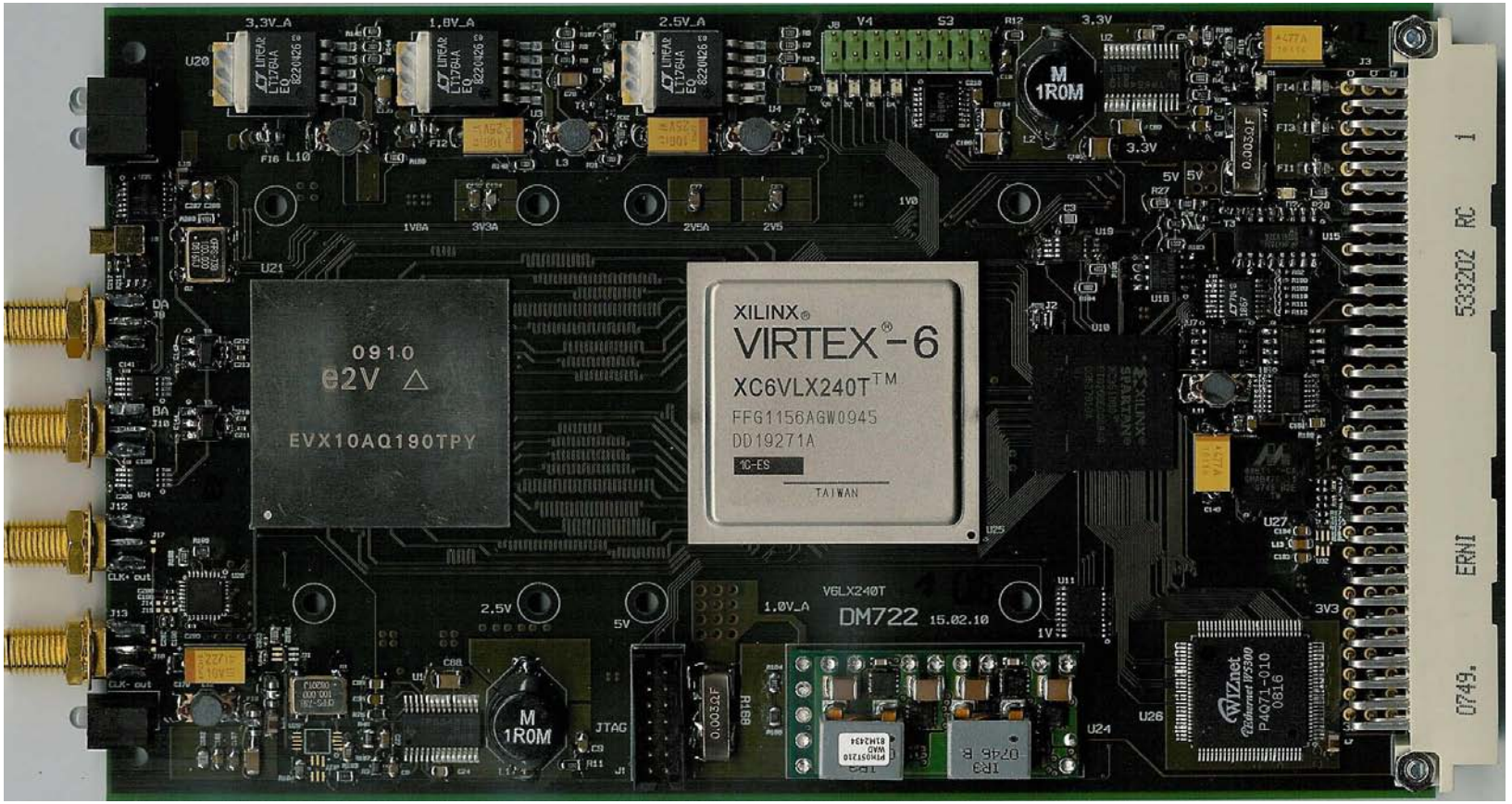
XFFTS: 2.5 GHz bandwidth / 32768 channels (ENBW 88.5 kHz)



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]

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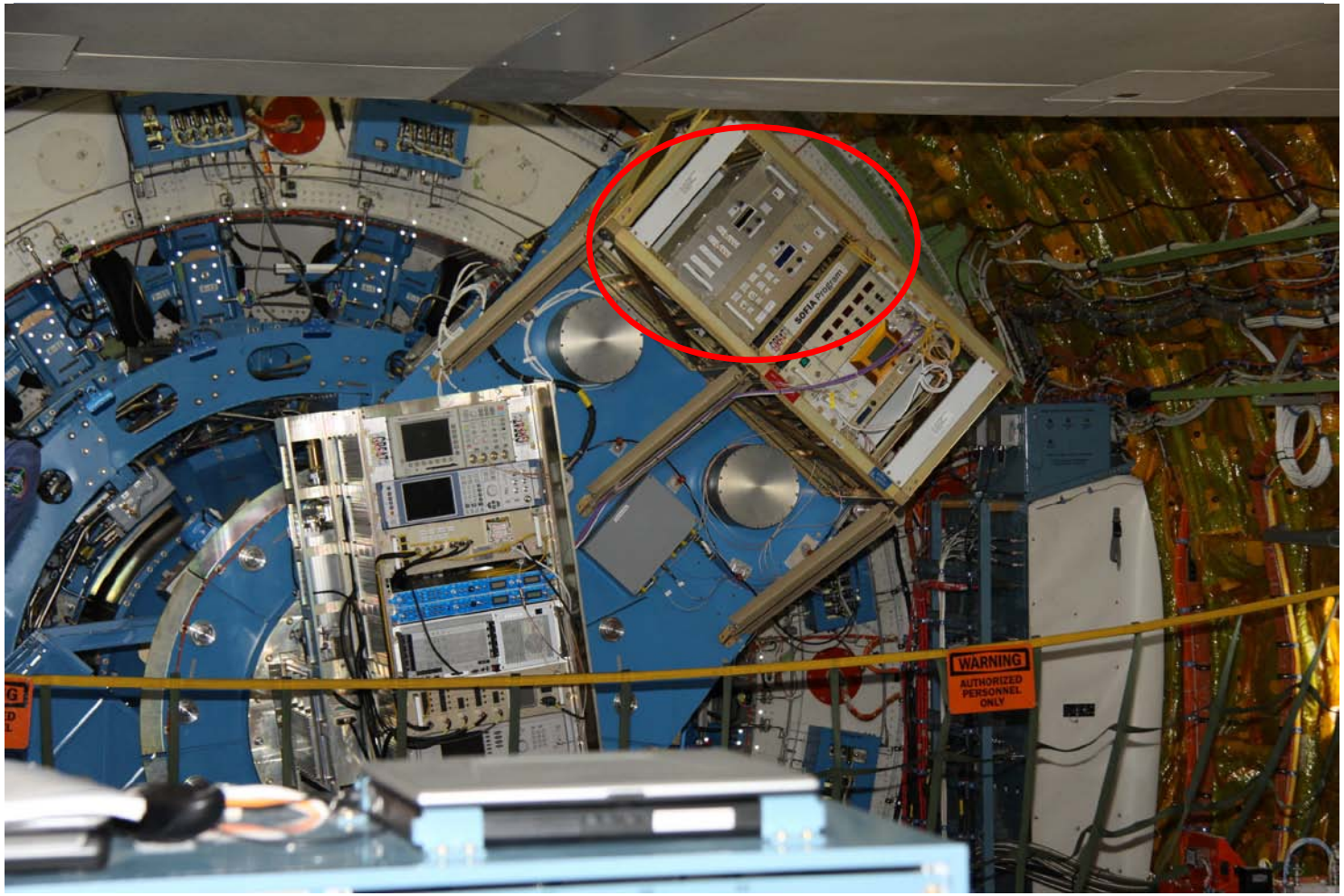
XFFTS :: *The Sofia spectrometer*

DIGITALLABOR

GREAT

FFTS/XFFTS: Sofia/GREAT installation



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XFFTS @ APEX

Atacama Pathfinder EXperiment
APEX

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

Installation & Commissioning: June 2010

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für Radioastronomie

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XFFTS @ APEX :: *IF-Processor*

Atacama Pathfinder EXperiment
APEX

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

Installation & Commissioning: June 2010

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APEX :: Flash345 + XIF + XFFTS

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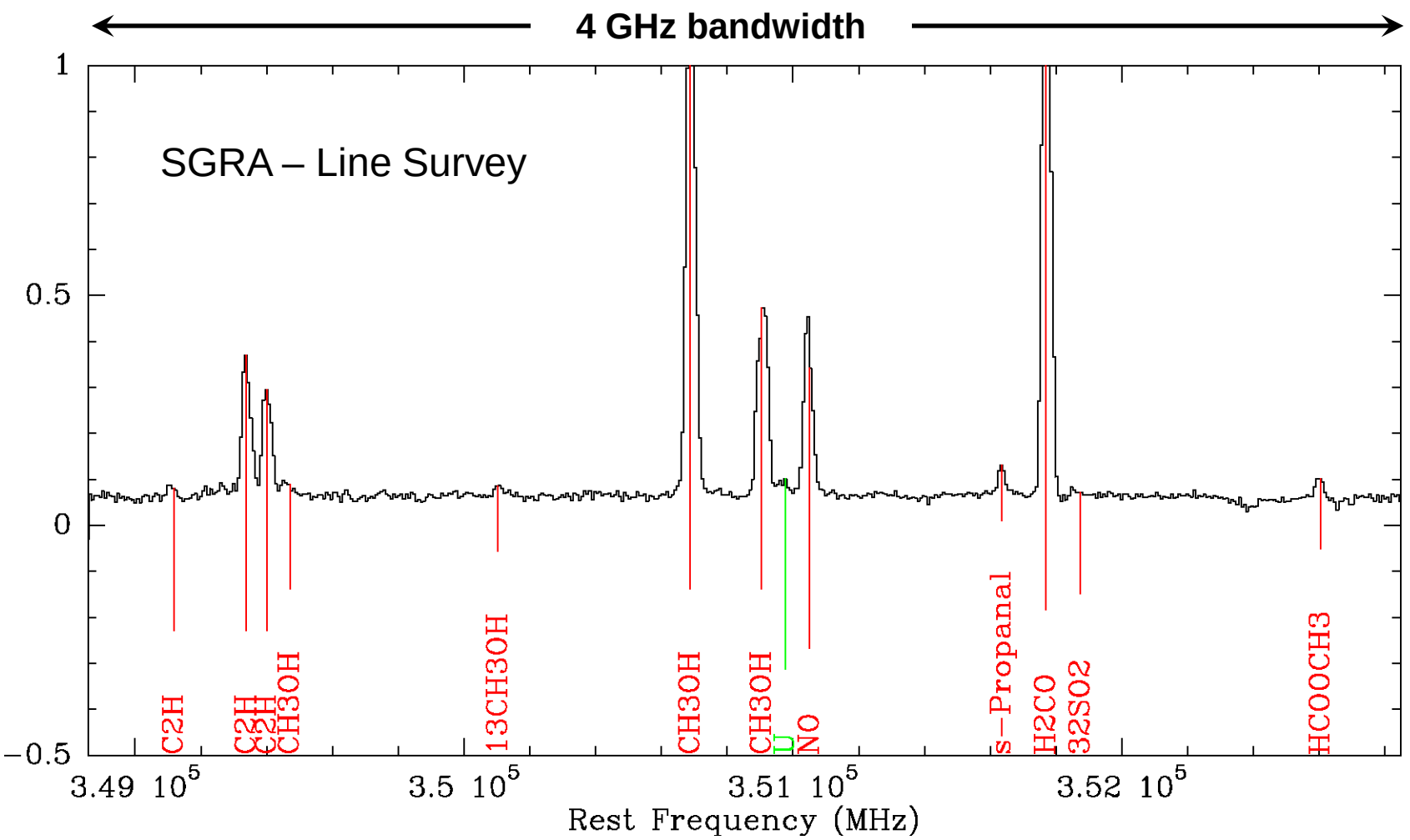
Atacama Pathfinder EXperiment
APEX



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APEX :: Flash345 + XIF + XFFTS

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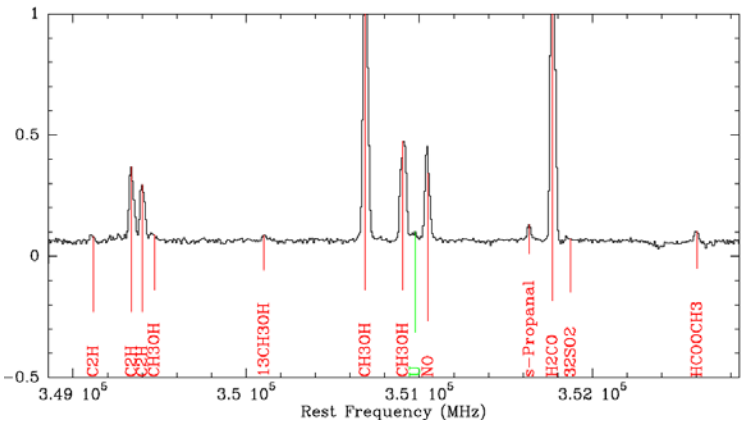
Atacama Pathfinder EXperiment
APEX

8 GHz of bandwidth in one setup

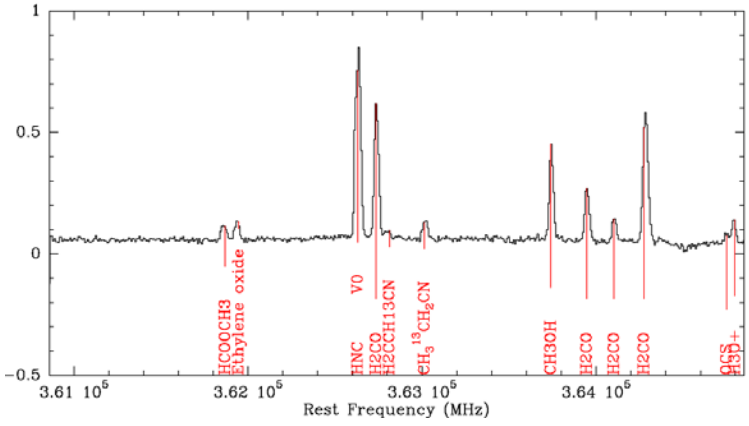
lower sideband

4 GHz bandwidth



upper sideband

4 GHz bandwidth



12 GHz spacing

Flash345: updated receiver with IRAM 2SB SIS mixer

iram
Institut de Radioastronomie Millimétrique

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NEW!

XFFTS-64K :: 65536 spectral channels

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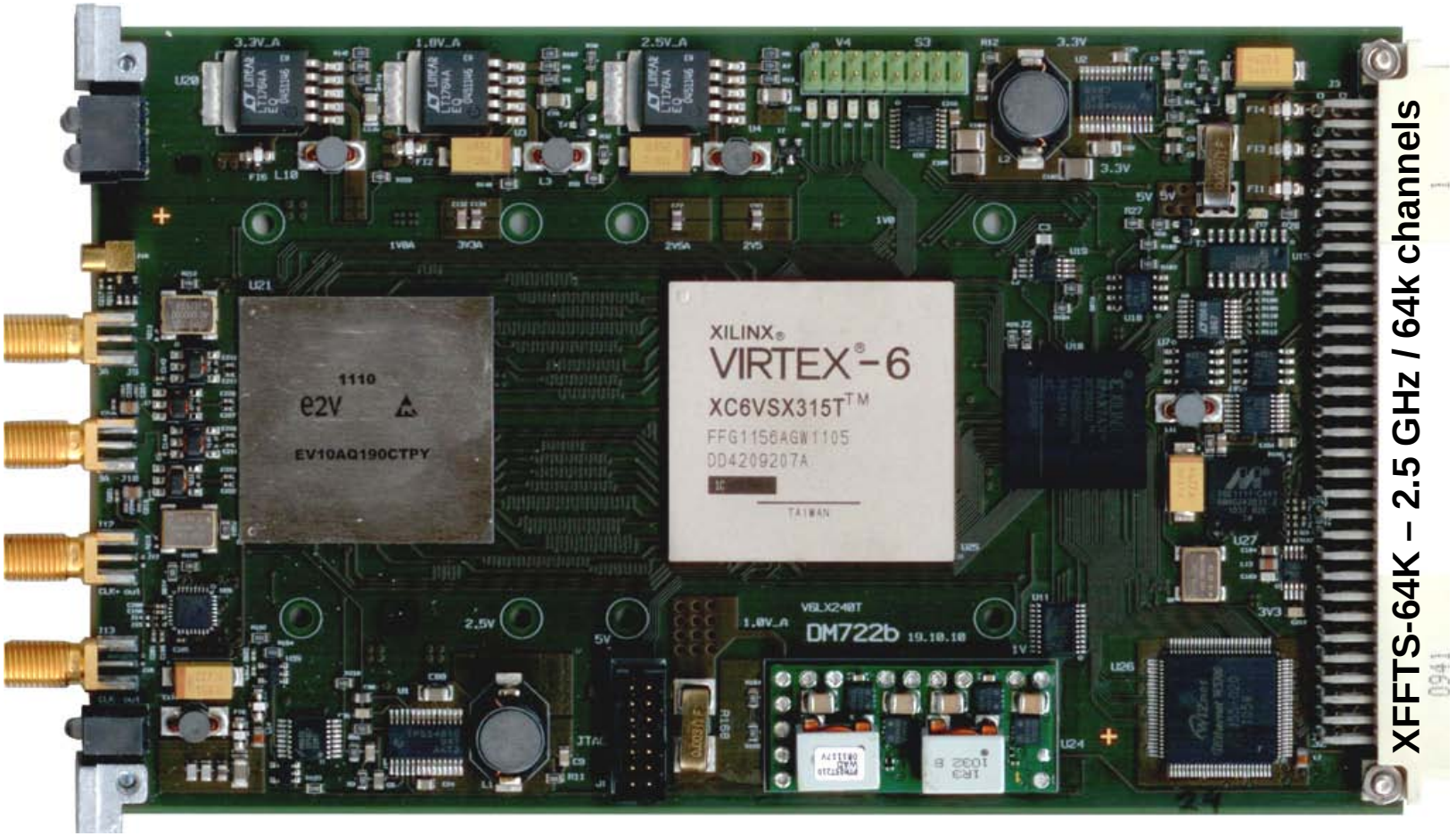
XFFTS: 2.5 GHz bandwidth / 65536 channels (ENBW 44 kHz)



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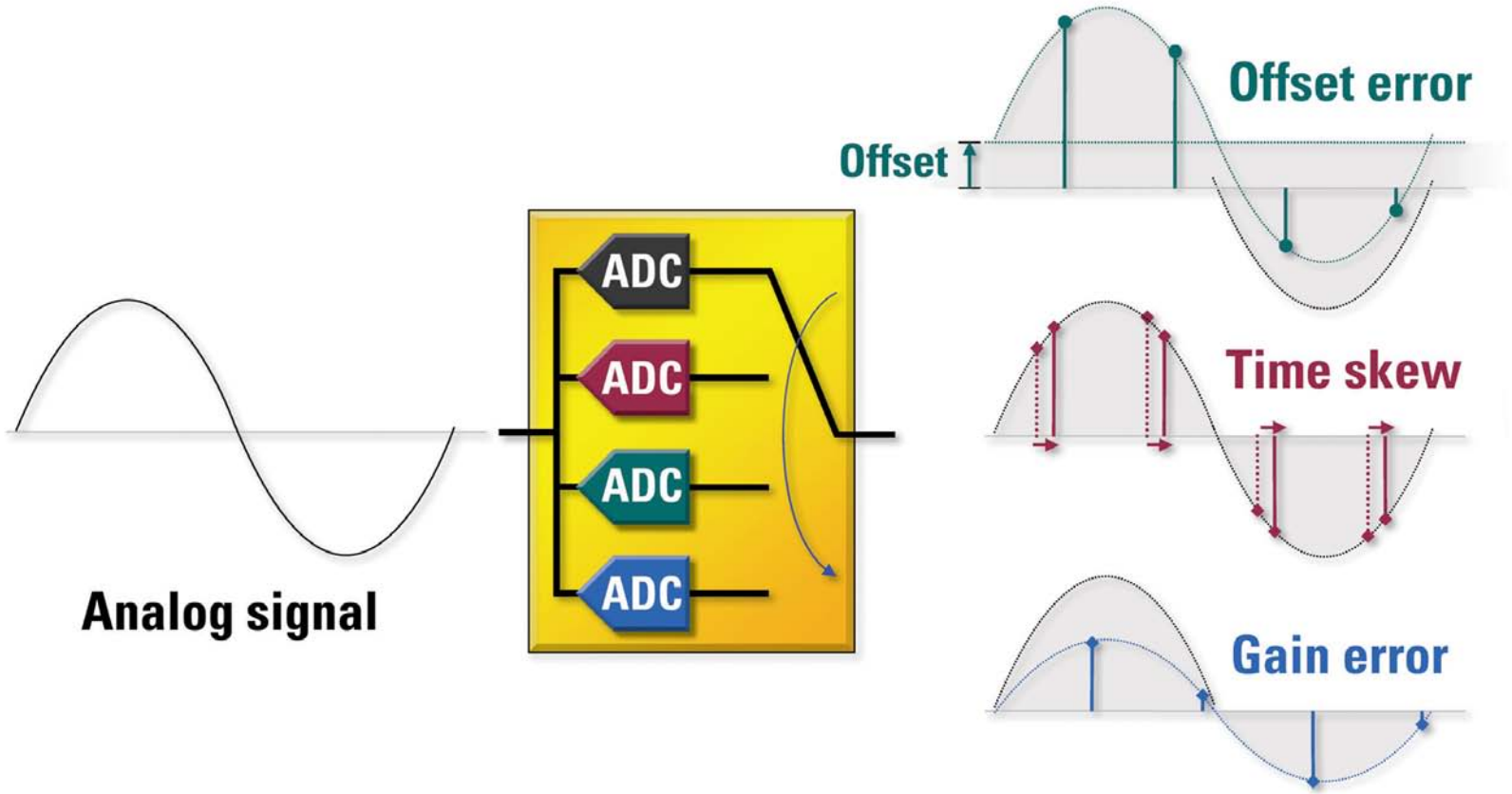
XFFTS :: *ADC interleaving*

ADC: e2v scientific instruments **10-Bit, 4 x 1.25 GS/s**



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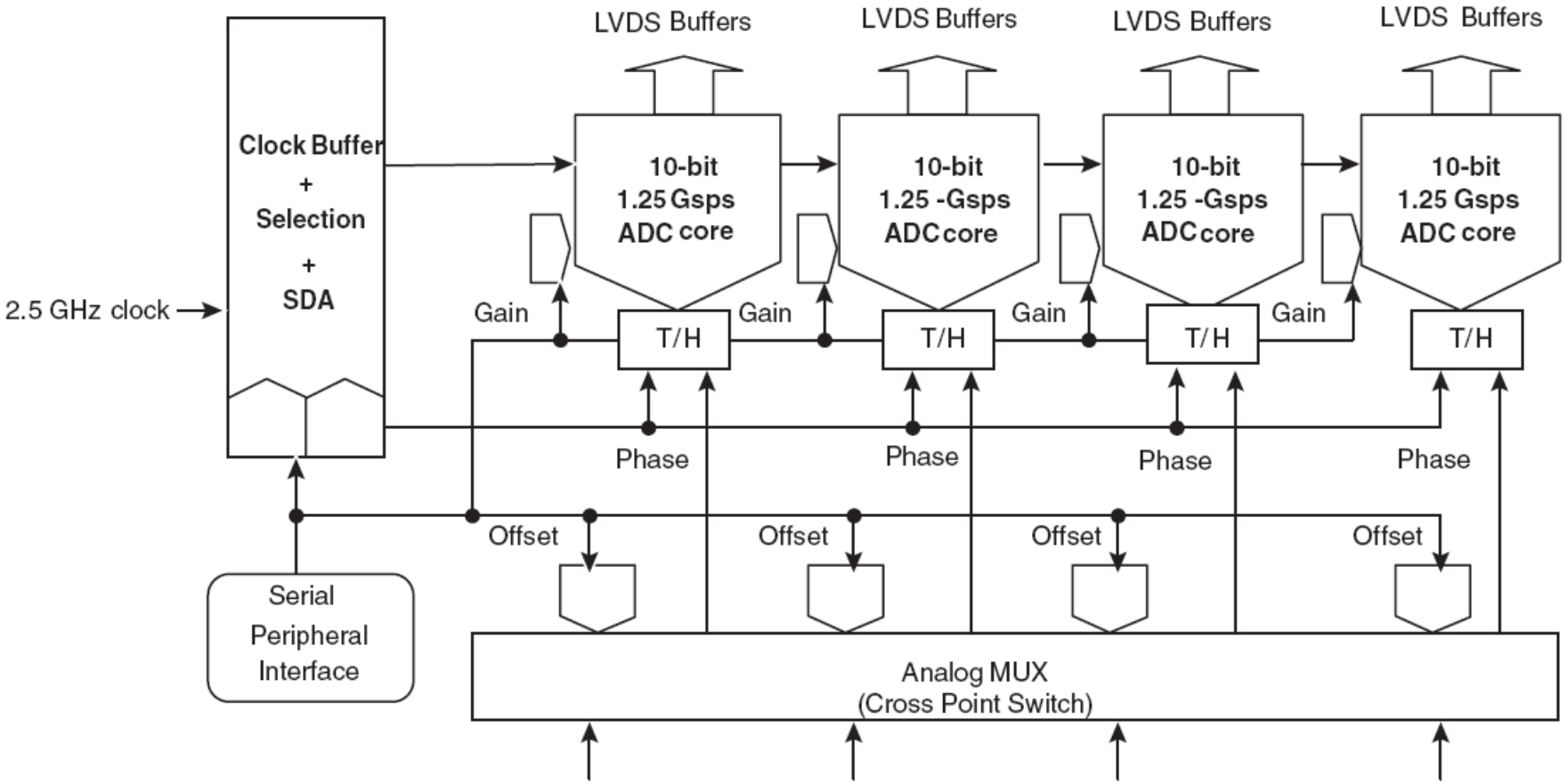

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XFFTS :: *ADC interleaving*

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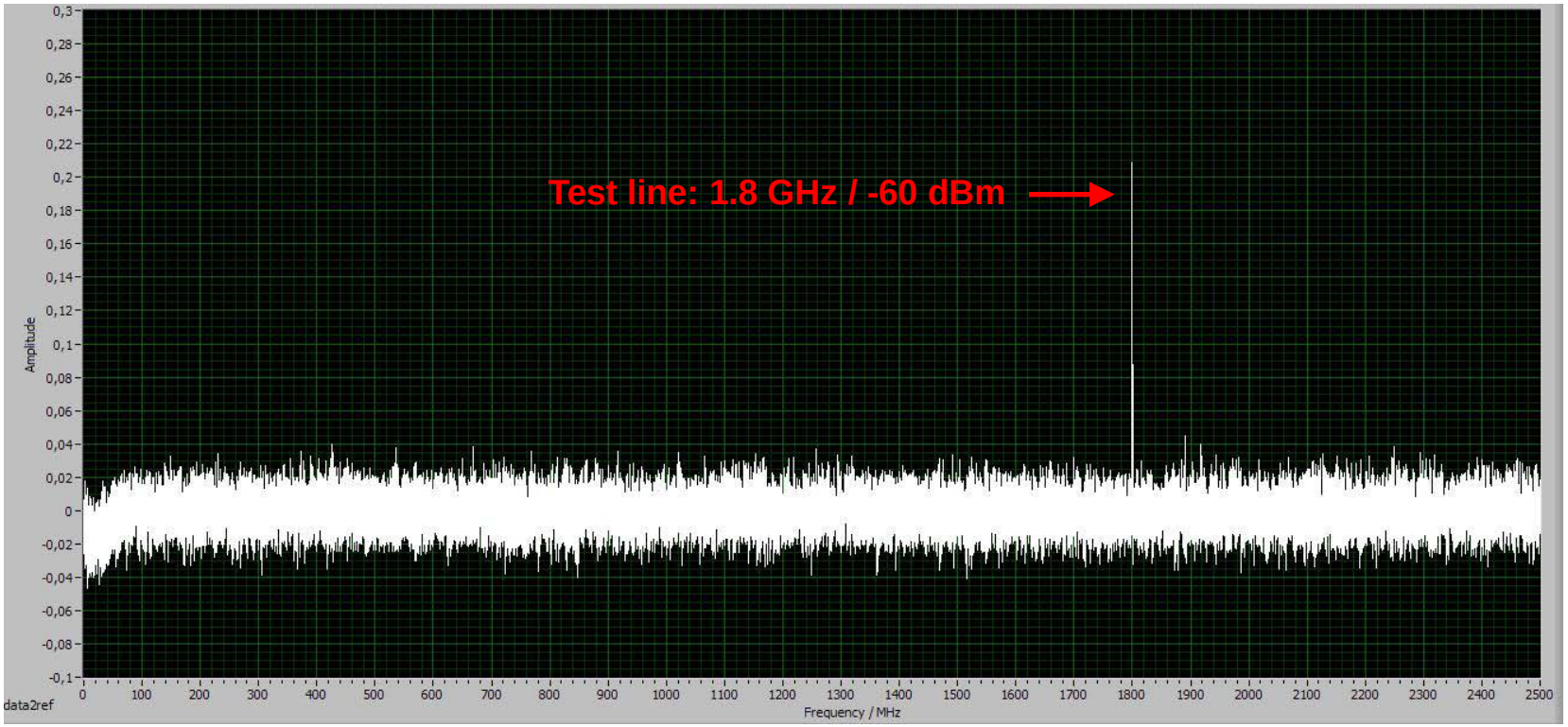
XFFTS: 2.5 GHz bandwidth / 10-bit / 32768 channels (ENBW 88.5 kHz)



2.5 GHz instantaneous bandwidth

FFT-Spectrometer :: *An Outlook*

EV5AS210 Series ADC

e2v

5-bit 20Gsps ADC with 8GHz input bandwidth

New ADCs: e.g., EV5A210 from E2V

- **20 GS/s sampling, 8 GHz Nyquist bandwidth**
- **5 bit resolution, effective bits (ENOB): > 4.5 @ 4 GHz**
- **8 GHz analog bandwidth, allows direct IF sampling**
- **But – is this highly interleaved ADC good enough for Radioastronomy ??? We will try…**

Key

e2v in
600m
DDR
CML
10GH
Digita

55

25x25

Output mode selection (data only, PRBS only, scrambled data)

Gain (+/-10%), Offset (+/-30mV), per channel delay adjust (0-10ps), test modes…

Analog Input Bandwidth: 8GHz (at -3dBFs)

Power supply: 3.3V

Power dissipation: 10W

Preliminary Performances

Full power input bandwidth (-3dB): 8GHz

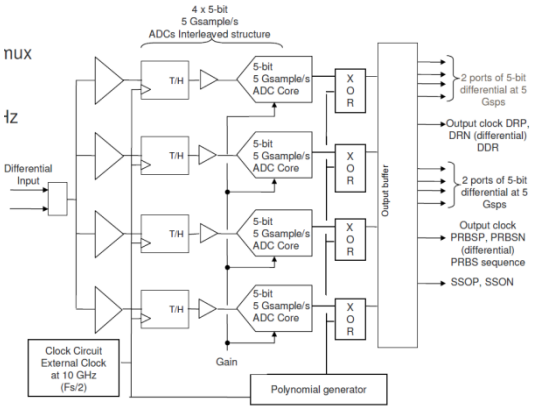
Sampling = 20Gsps, Fin = 4GHz

ENOB = 4.5 Bit

SFDR = 35dBc

Availability:

Demonstrator prototypes: **Now**



FFT-Spectrometer :: *An Outlook*

Hittite MICROWAVE CORPORATION v00.0709

HMC5448

8-BIT, 5 GS/s ANALOG-TO-DIGITAL CONVERTER

Typical Applications

The HMC5448 is ideal for:

- RF Test Instruments and ATE
- Digital Sampling Oscilloscopes
- Radar / Lidar Systems
- Software Defined Radio and Digital Receivers

Features

~~8-bit Resolution~~

>6 GHz Input Bandwidth

~~>5 GS/s Sampling Rate~~

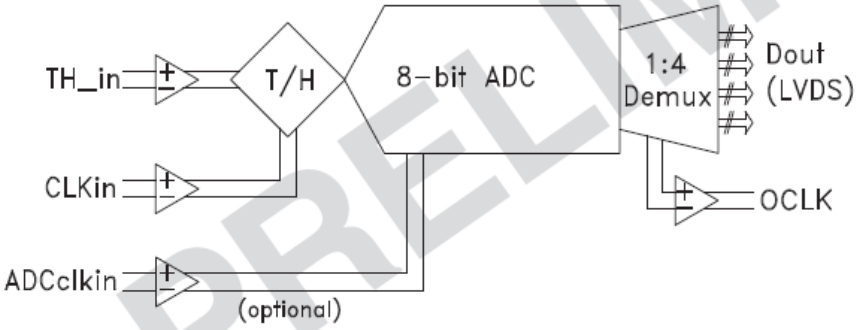
Direct-coupled Differential Signal, Clock Inputs

1:4 LVDS-compatible Output Data Demux

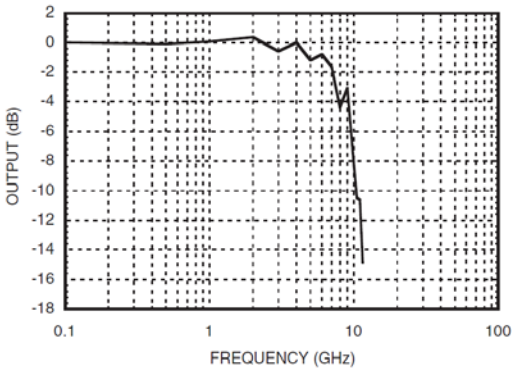
Synchronous Output Clock, Over-range Bit

16 x 16 pin (17 x 17 mm²) BGA Package

Functional Diagram



Input Bandwidth [1]



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FFT-Spectrometer :: *IF sampling*

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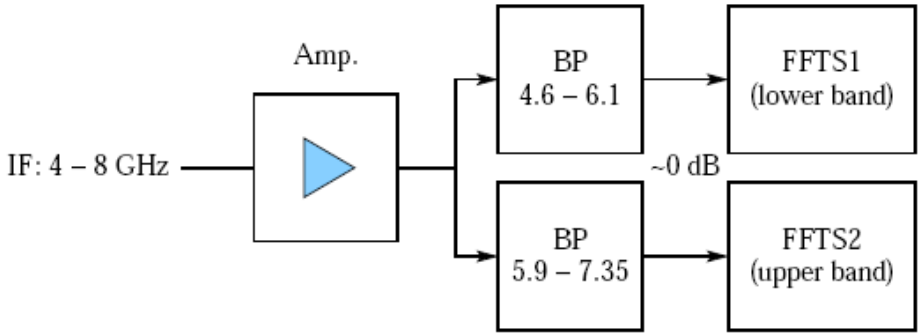

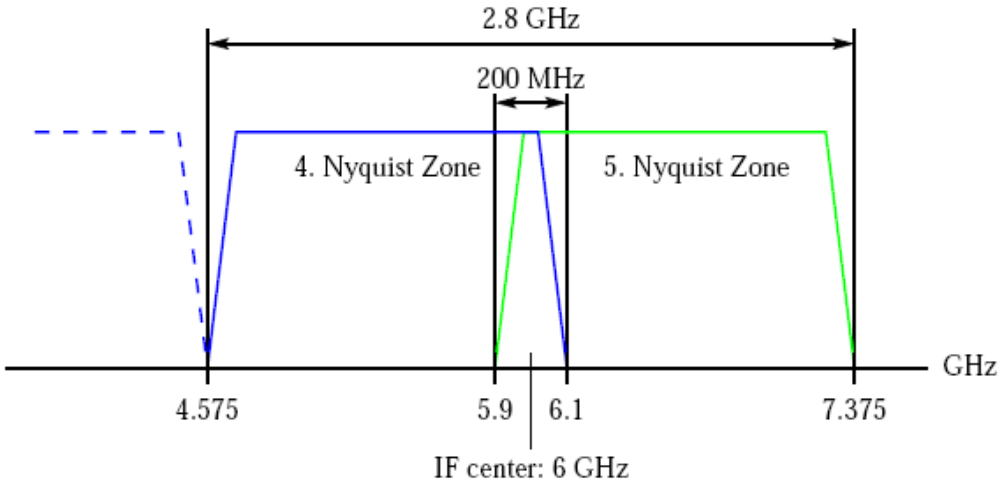

Lower Bandwidth: 1.475 / Frequency Spacing @ 2K channels: 0.720 MHz

Upper Bandwidth: 1.525 / Frequency Spacing @ 2K channels: 0.745 MHz

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FFT-Spectrometer :: *Summary*

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 5 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.

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FFTS/XFFTS :: *Contact, Distribution*

Contact:

For further information about the MPIfR FFT spectrometer, future developments and applications, please contact
Prof. Bernd Klein (bklein@mpifr.de) or
Dr. Rolf Güsten (rguesten@mpifr.de) at the
Max-Planck-Institut für Radioastronomie in Bonn, Germany.

Distribution:

NEW!

Radiometer Physics GmbH

http://www.radiometer-physics.de

NEW!