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DIGITALLABOR

Fast Fourier Transform Spectrometer (FFTS)

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- Germany -

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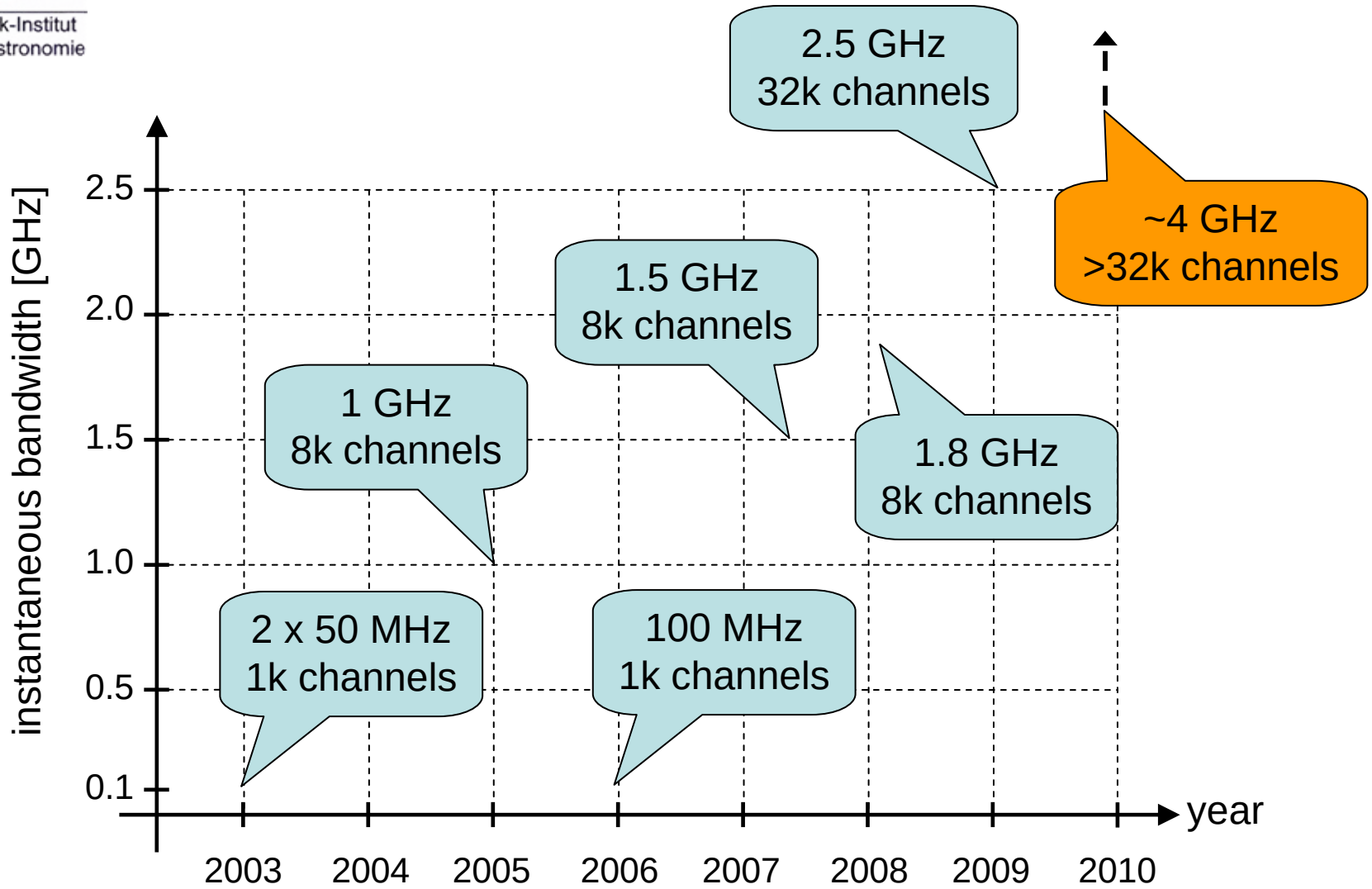
Improvement in bandwidth by a factor of 50 over 6 years or >400 MHz per year!



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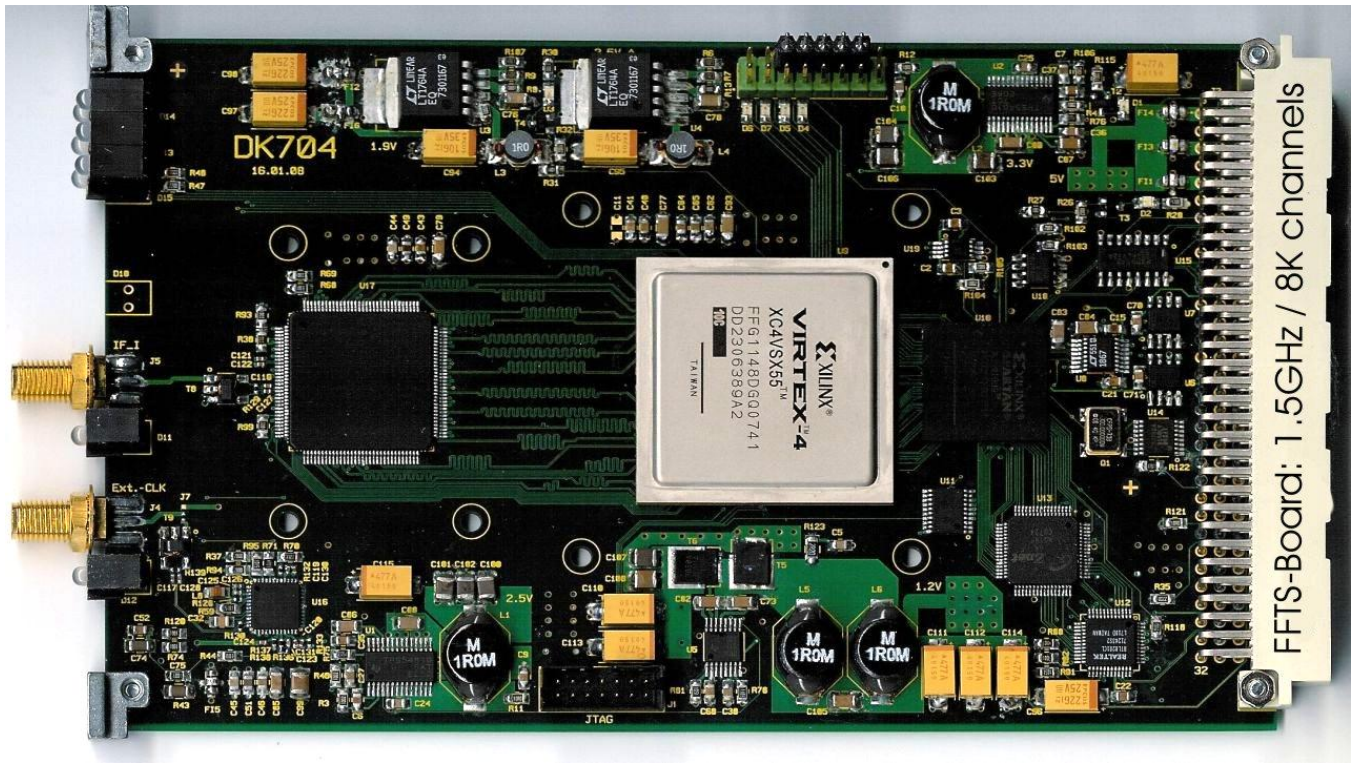
FFTS :: *The MPIfR-Board*

IF input
(0 - 3 GHz)



5 Volt

Data

- Instantaneous bandwidth: 0.1 – 1.8 GHz
- Spectral resolution @ 1.5 GHz: 212 kHz
- Stability (spec. Allan Variance): > 1000 sec.
- Calibration- and aging free digital processing

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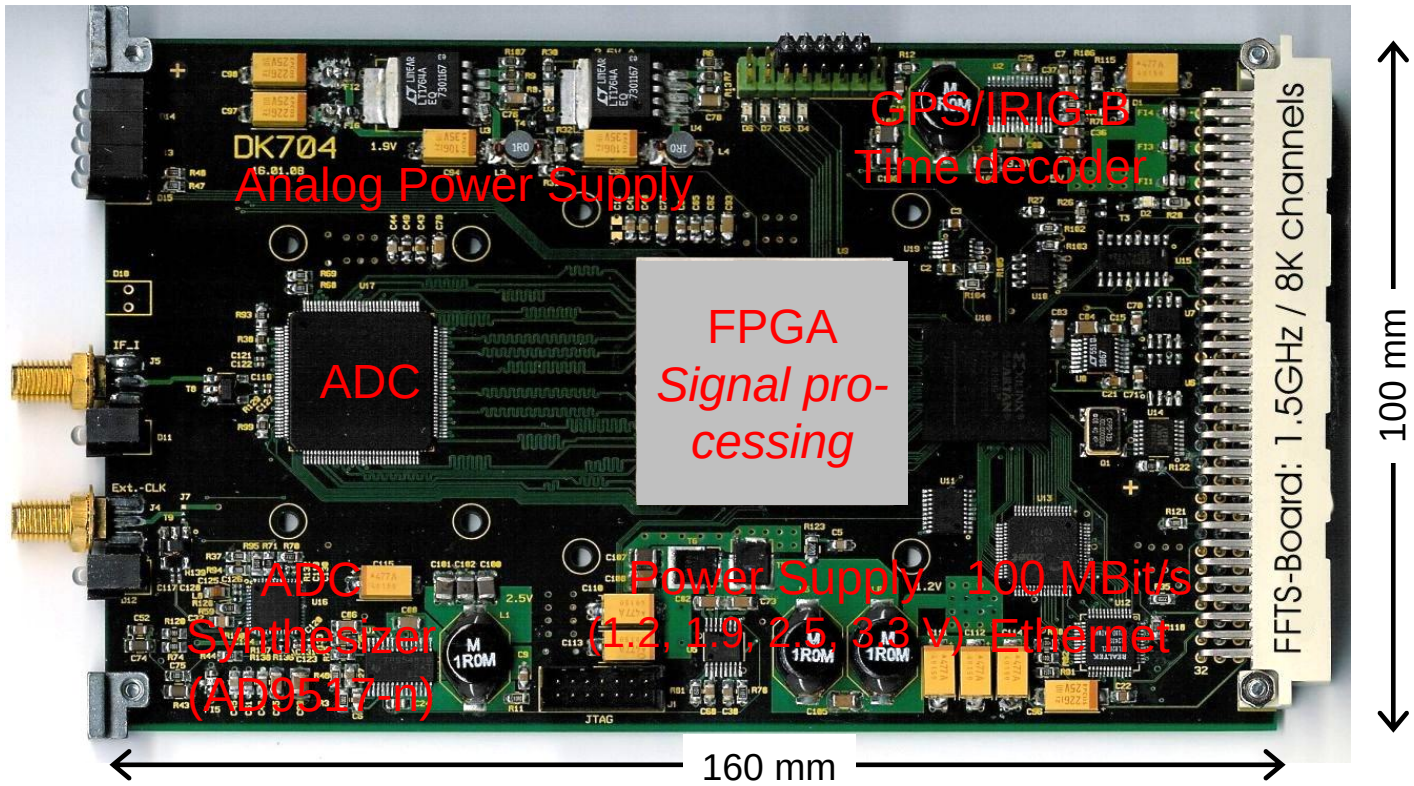
FFTS :: *The MPIfR-Board*



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APEX :: *Atacama Pathfinder EXperiment*

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Telescope:

Location:	Llano de Chajnantor, 50 km east San Pedro de Atacama, northern Chile
Coordinates:	Latitude : 23º00"20.8' South Longitude :67º45'33.0" West Elevation : 5105 m
Diameter:	12 m
f/D:	8
Beam width:	(FWHM) 7.8" * (800 / f [GHz])
Main reflector:	264 aluminum panels, average panel surface rms 5 micron
Surface accuracy:	17 micron rms
Pointing accuracy:	2" rms over sky
Mounting:	Alt-Az
Receiver cabins:	2 Nasmyth + 1 Cassegrain
Mass:	125 000 kg
Manufacturer:	Vertex Antennentechnik

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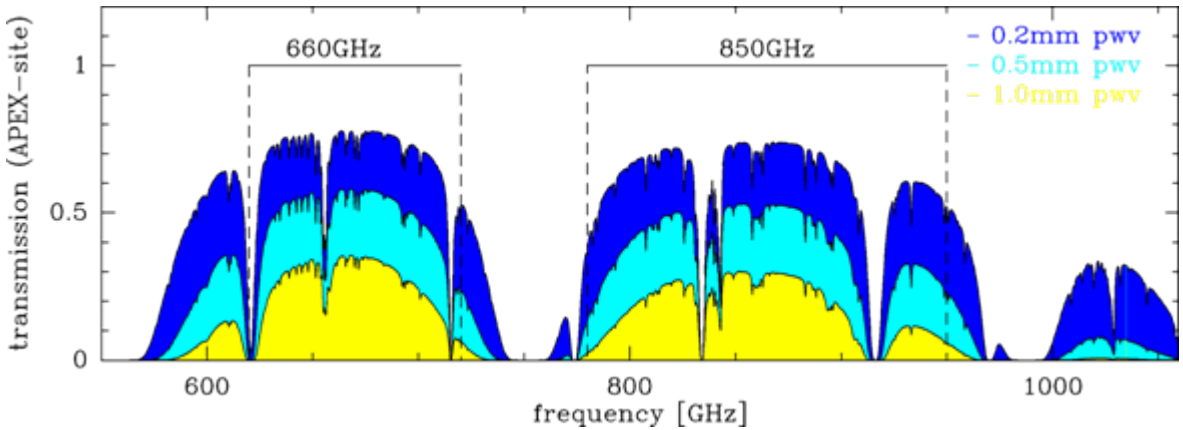
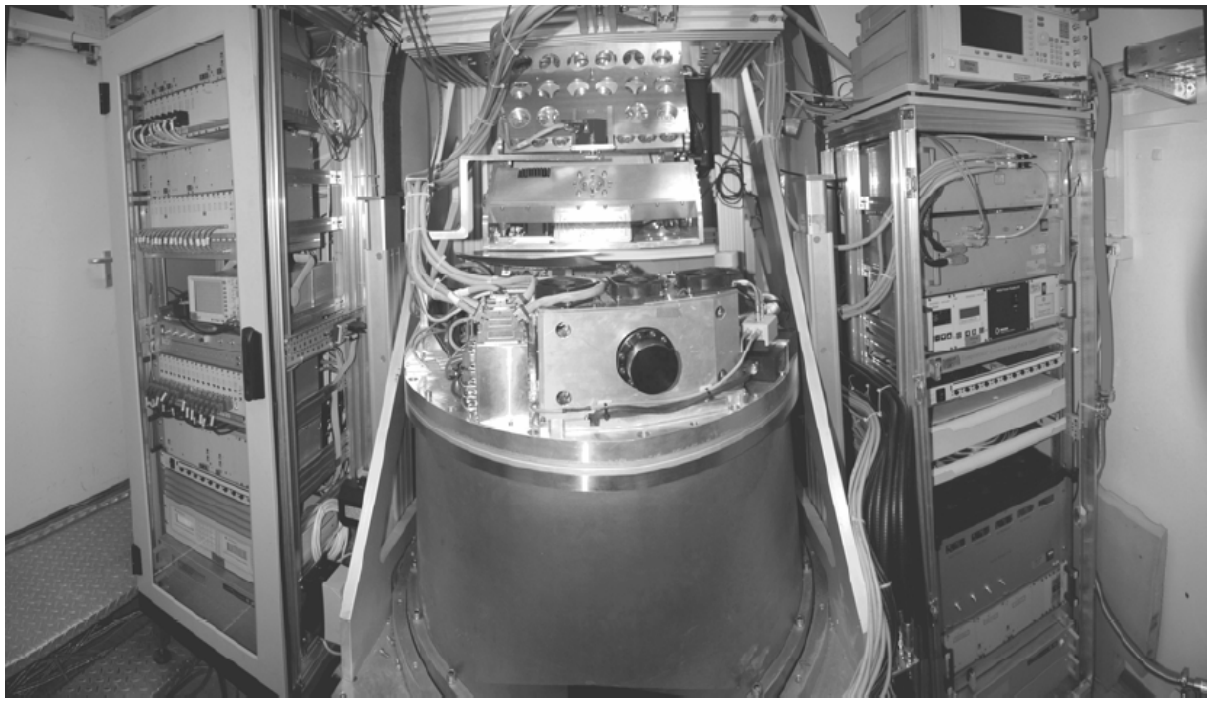
CHAMP+ :: Array-RX 660/850 GHz window





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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 :: *Software / Monitoring*

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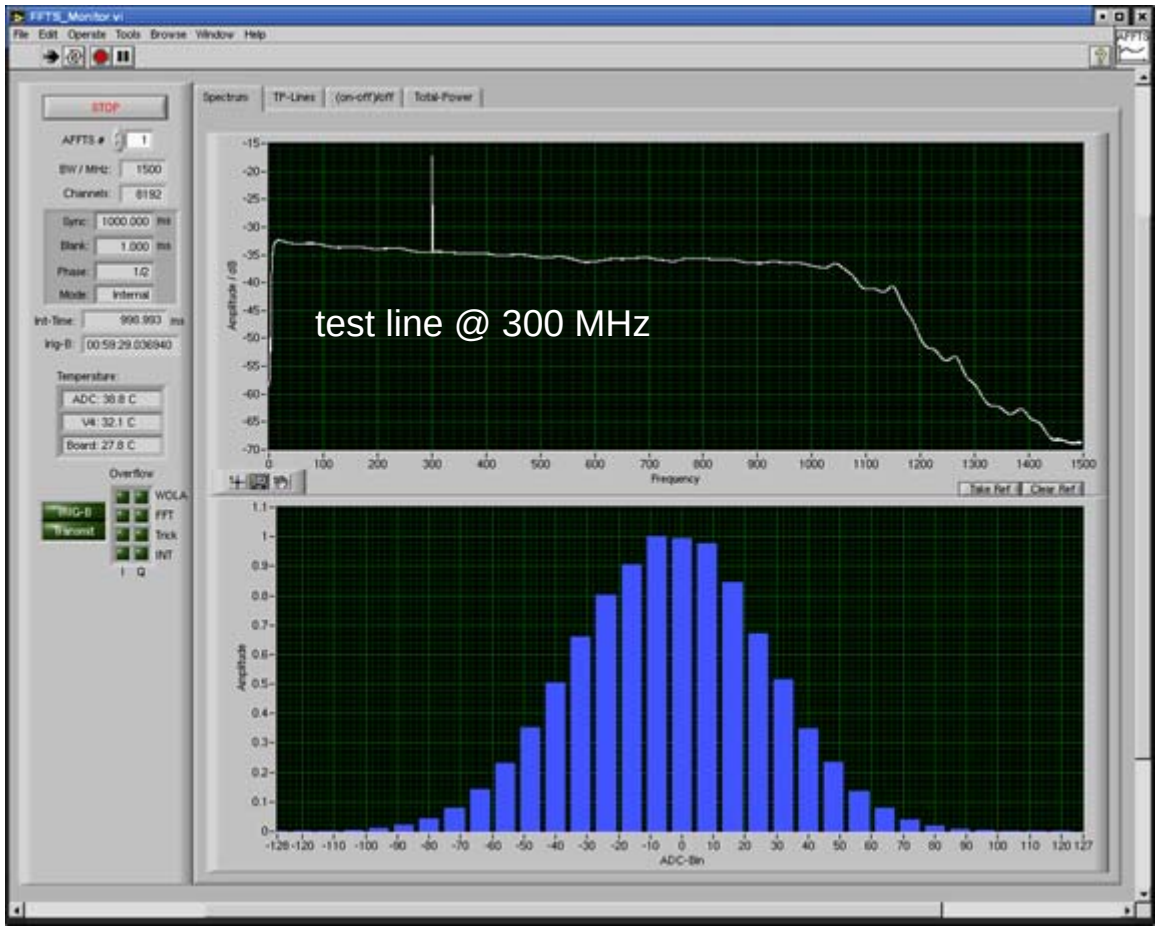
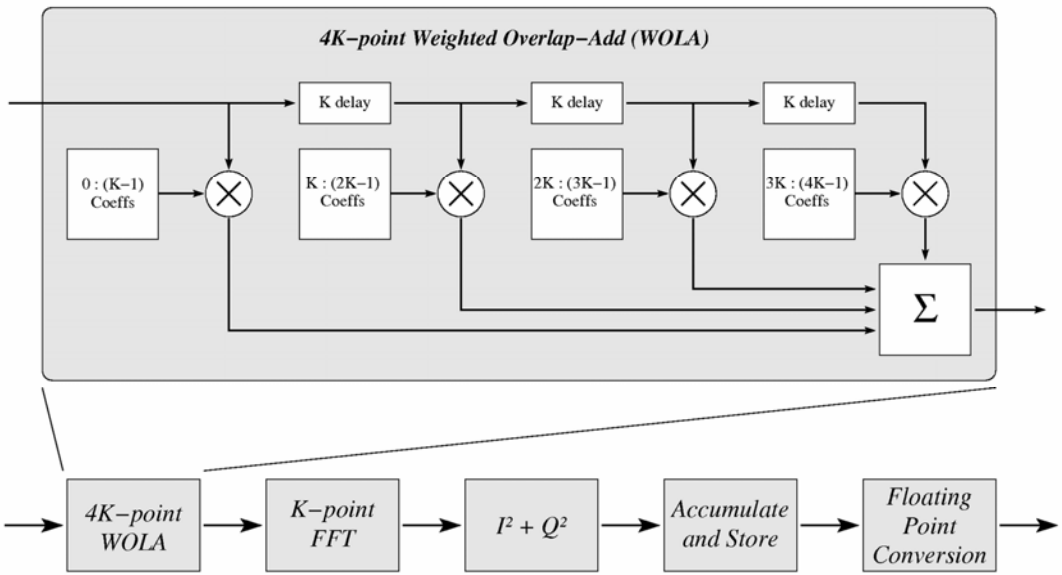


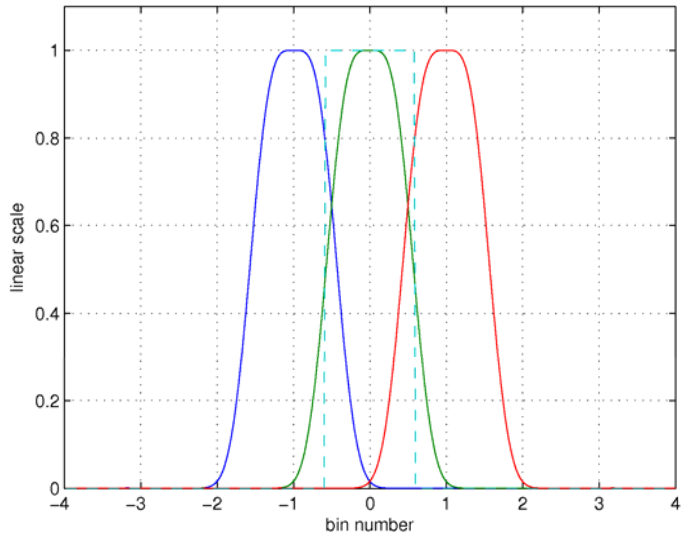
FFTS Control Software:

- multi-threaded software / Linux
- one thread per FFTS-board (smoothing, leveling, RFI-filter, ..)
- communication telescope / FFTS: SCPI protocol (UDP/ASCII), e.g.
  APEX:AFFTS:band1:cmdBandwidth 1500
- data flow: TCP (header + spectra)
- FFTS Monitor Tool (LabView)

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*

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

- 2 x 750 MHz bandwidth, 2 x 8192 spectral channels, ENBW: 107 kHz
- 2 x 500 MHz bandwidth, 2 x 8192 spectral channels, ENBW: 71 kHz
- 2 x 100 MHz bandwidth, 2 x 8192 spectral channels, ENBW: 14 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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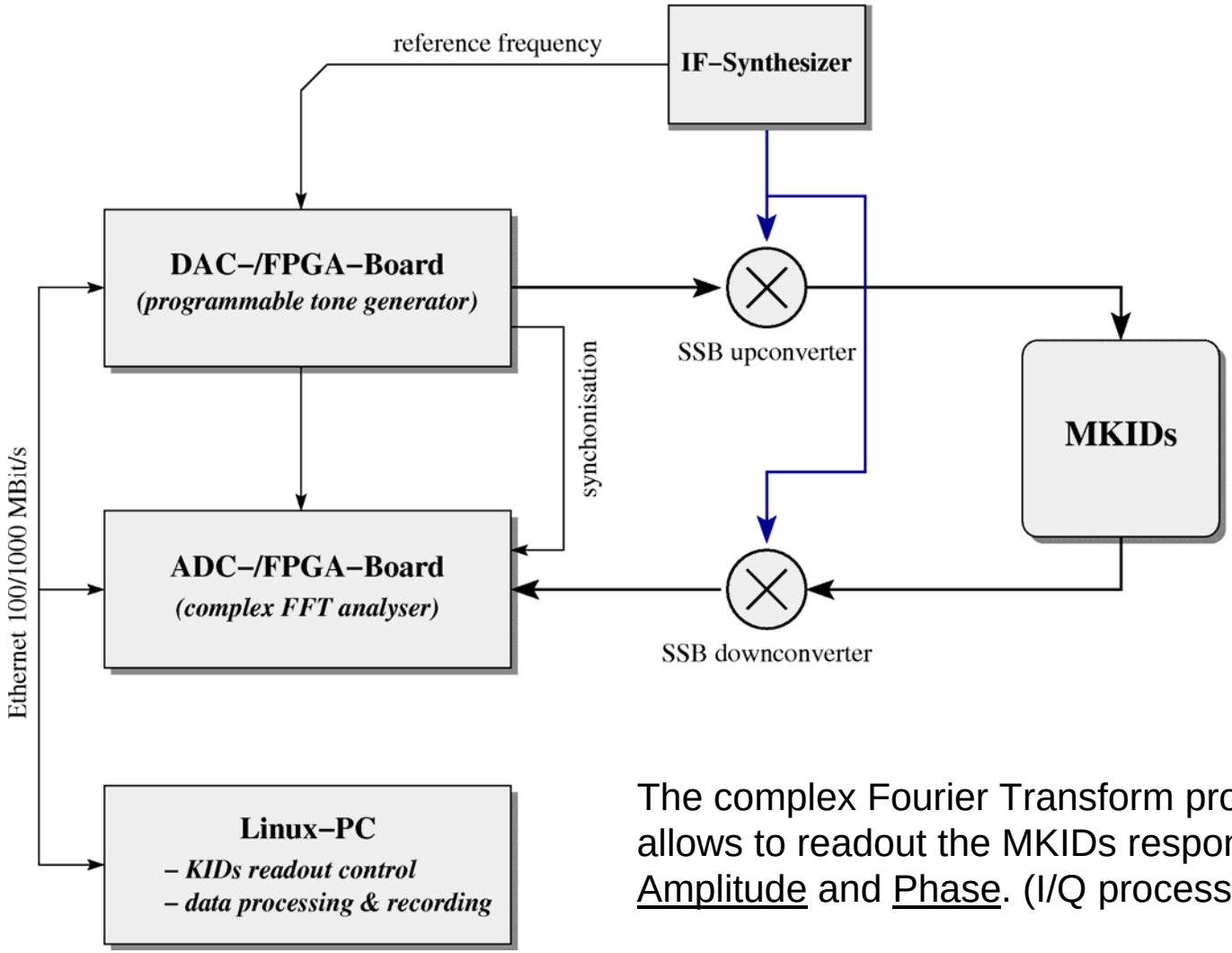
MKIDs Readout: *The Principle*



The complex Fourier Transform processing allows to readout the MKIDs response in Amplitude and Phase. (I/Q processing)

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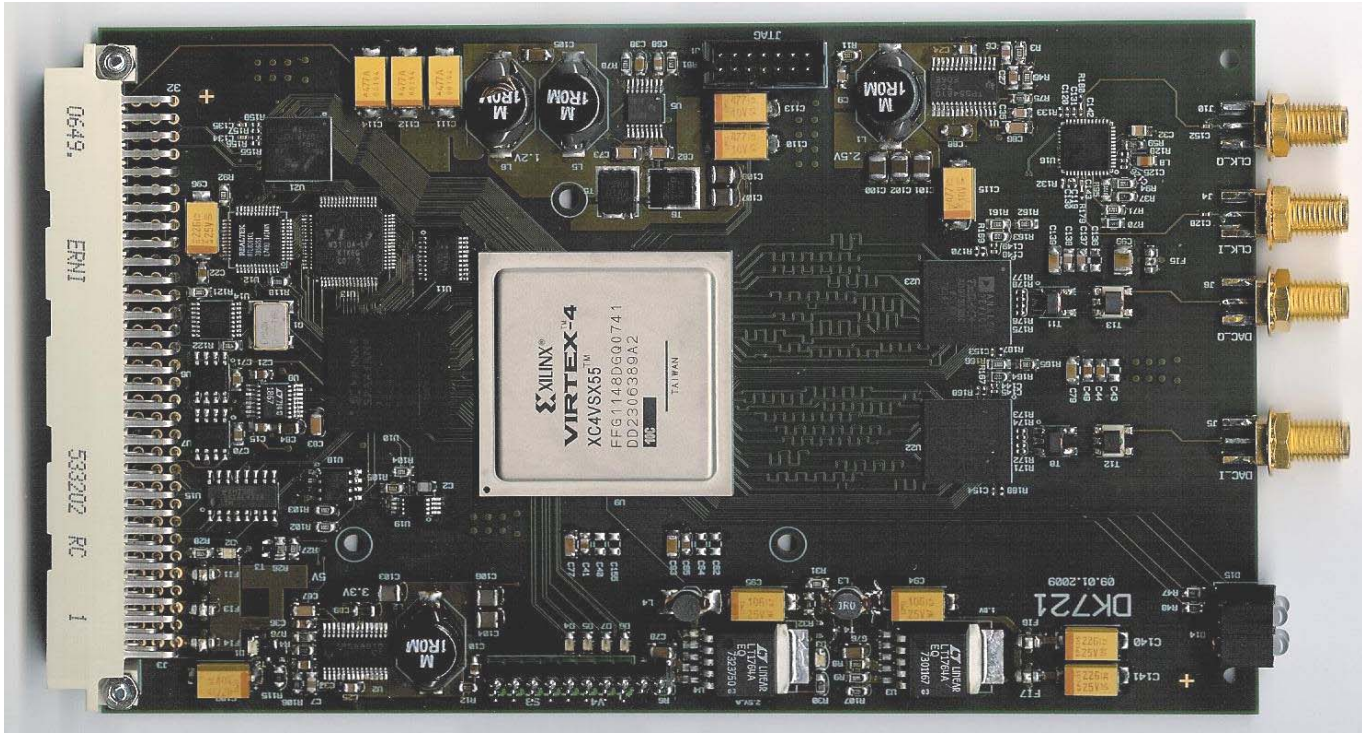
MKIDs Readout: *Prototype Hardware*

DAC-/FPGA-Board – The tone generator

TCP

(100 Mbits/s)



Clock

Sync

I-Output

Q-Output

- 2 x 400 MHz bandwidth
- 14-bit DAC dynamic
- 2 x 65536 frequency channels
- arbitrary-function is programmable by Ethernet

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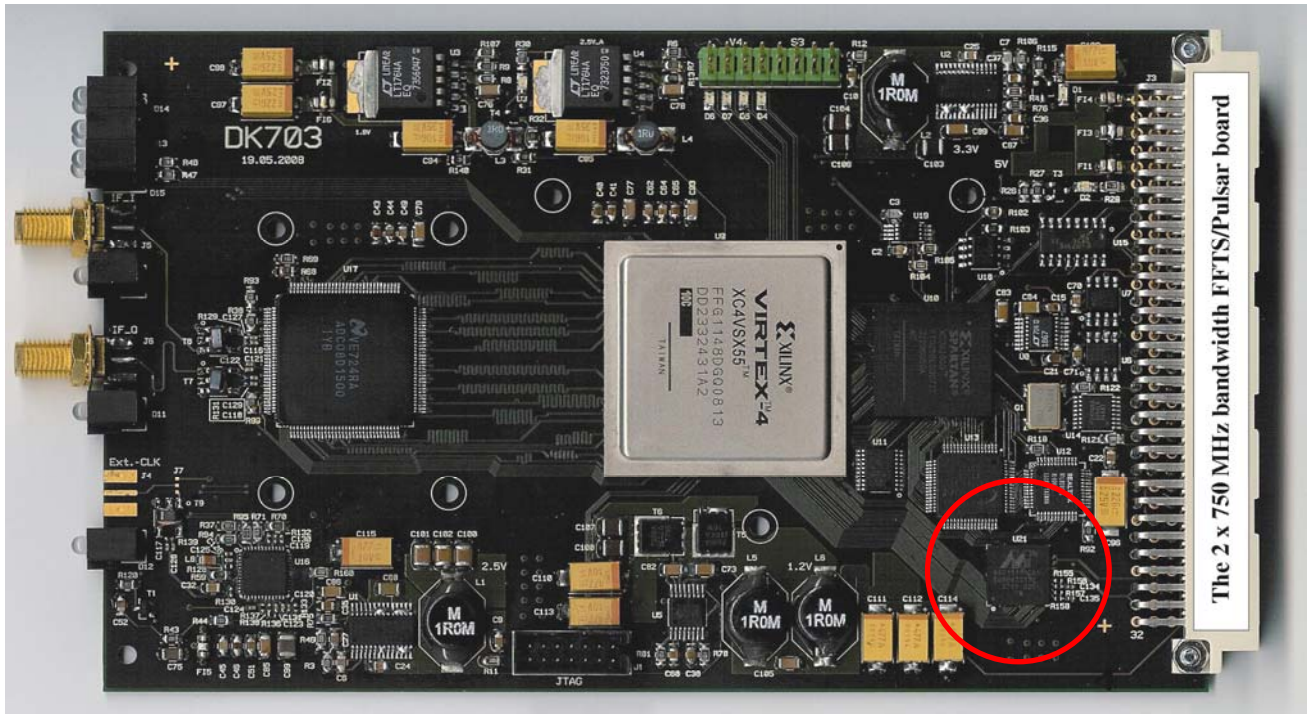
MKIDs Readout: *Prototype Hardware*

ADC-/FPGA-Board – The FFT analyser

I-Input

Q-Input

Clock



TCP 100 Mbits/s

UDP 1 Gbits/s

Marvell GigaBit chip

- 2 x 750 MHz bandwidth
- 8-bit ADC dynamic
- polyphase FFT processing
- up to 32768 complex (I/Q) frequency channels
- data transfer by 1000 MBit/s Ethernet

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GREAT-FFTS

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GREAT

Two operation modes:

- **Broadband :** 2x (4x) 1.8 GHz bandwidth / 2x (4x) 8192 channels, ENBW: 255 kHz
- **Narrowband:** 2x (4x) 750 MHz bandwidth / 2x (4x) 16384 channels, ENBW: 53 kHz

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XFFTS :: *The 2.5 GHz test board*

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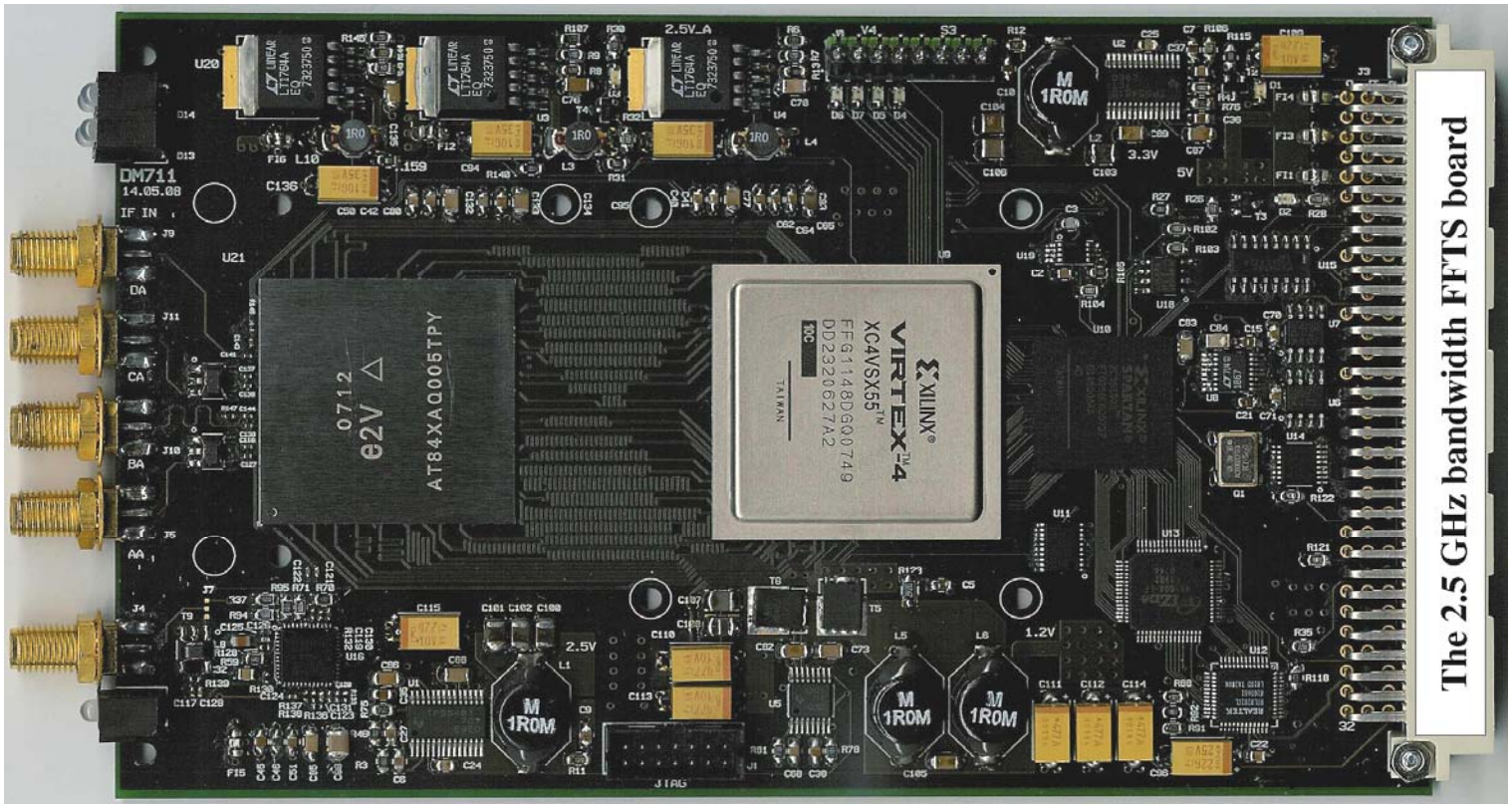
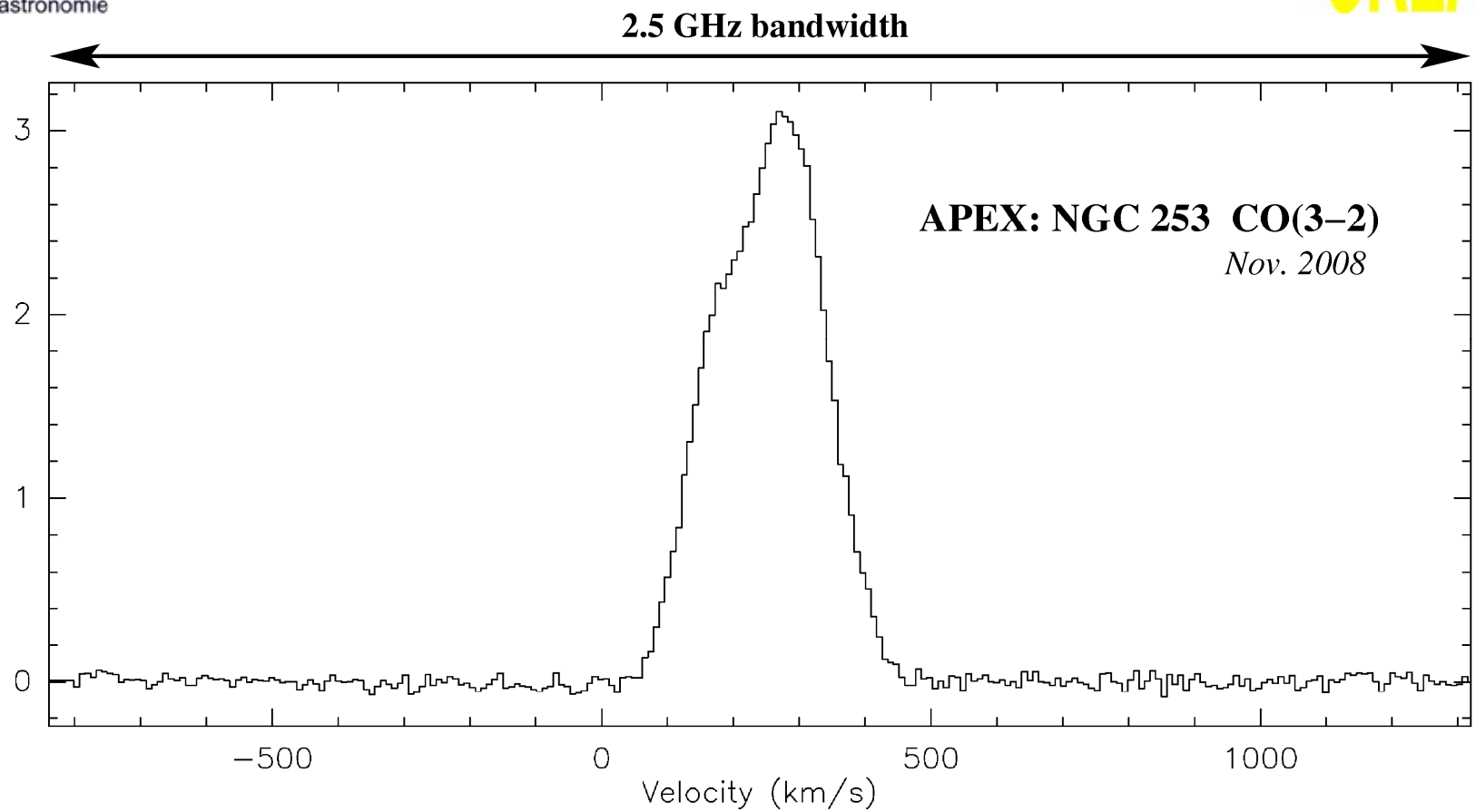
XFFTS: 2.5 GHz bandwidth / 256 channels (ENBW 11.3 MHz), 4 IF inputs



E2V 5 GS/s 8-bit ADC, XILINX Virtex-4 SX55

XFFTS :: *First light at APEX*



First light spectrum of the new MPIfR 2.5 GHz bandwidth XFFTS towards NGC 253. The CO(3–2) transition at 345 GHz was observed with the APEX-2 facility receiver in November 2008.

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XFFTS :: *The new 10-bit 5 GS/s ADC*

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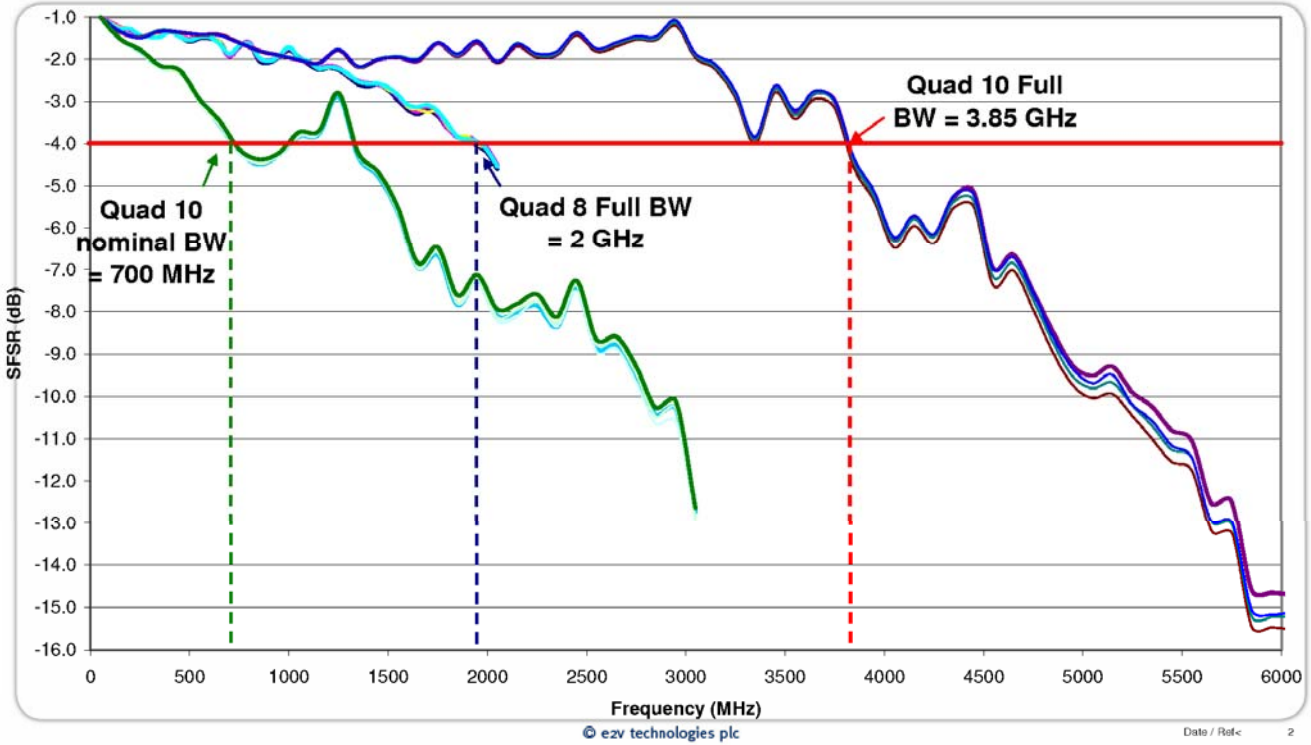
ADC QUAD 10bit

e2v

Quad 10 Bandwidth @ Fc = 2.5 GHz



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XFFTS :: *The new 10-bit 5 GS/s ADC*

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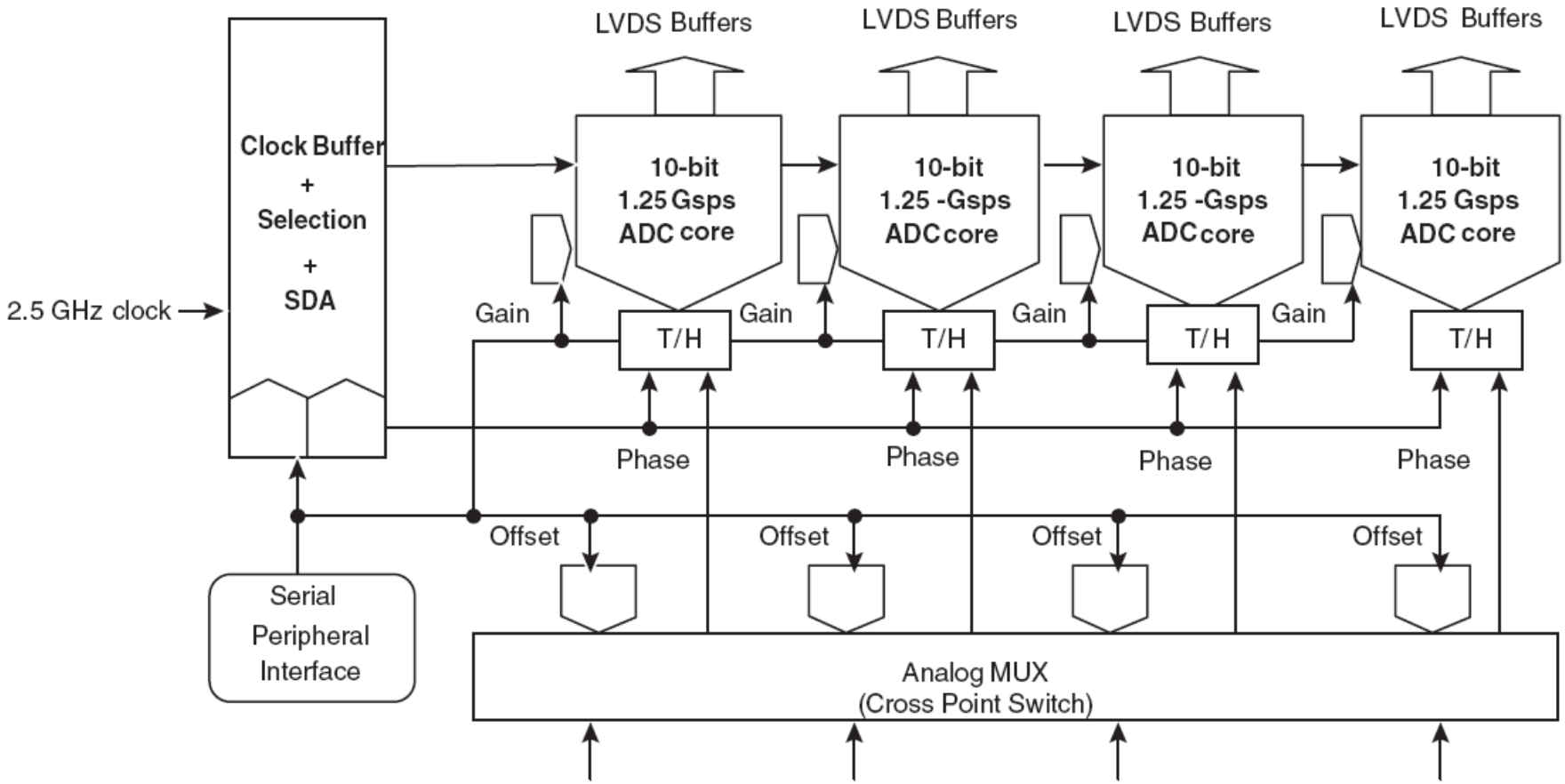

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XFFTS :: *The newest board*

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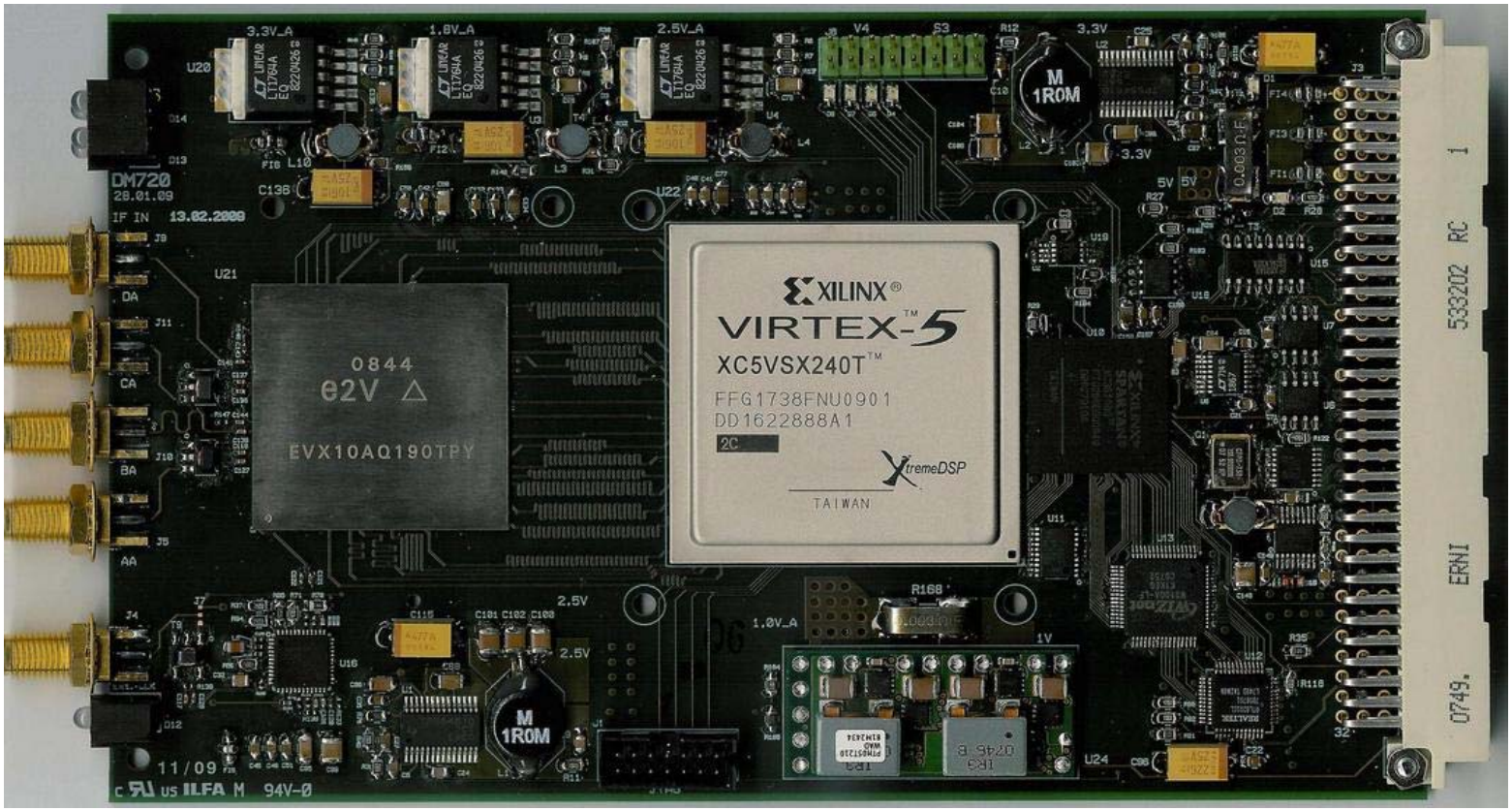
XFFTS: 2.5 GHz bandwidth / 32768 channels (ENBW 88.5 kHz), 4 IF inputs



E2V 5 GS/s 10-bit ADC, XILINX Virtex-5 SX240T

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XFFTS :: *The first lab spectra*

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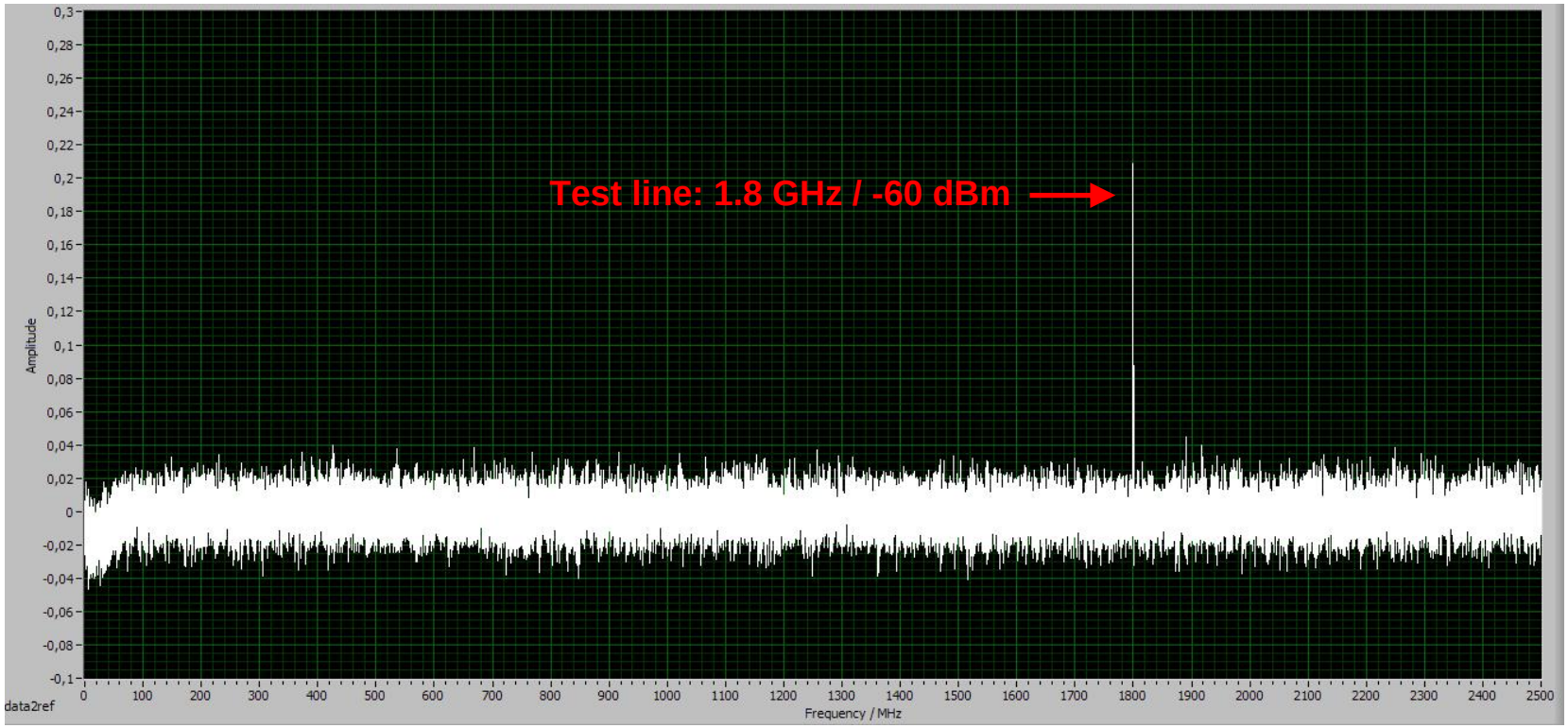
XFFTS: 2.5 GHz bandwidth / 10-bit / 32768 channels (ENBW 88.5 kHz)

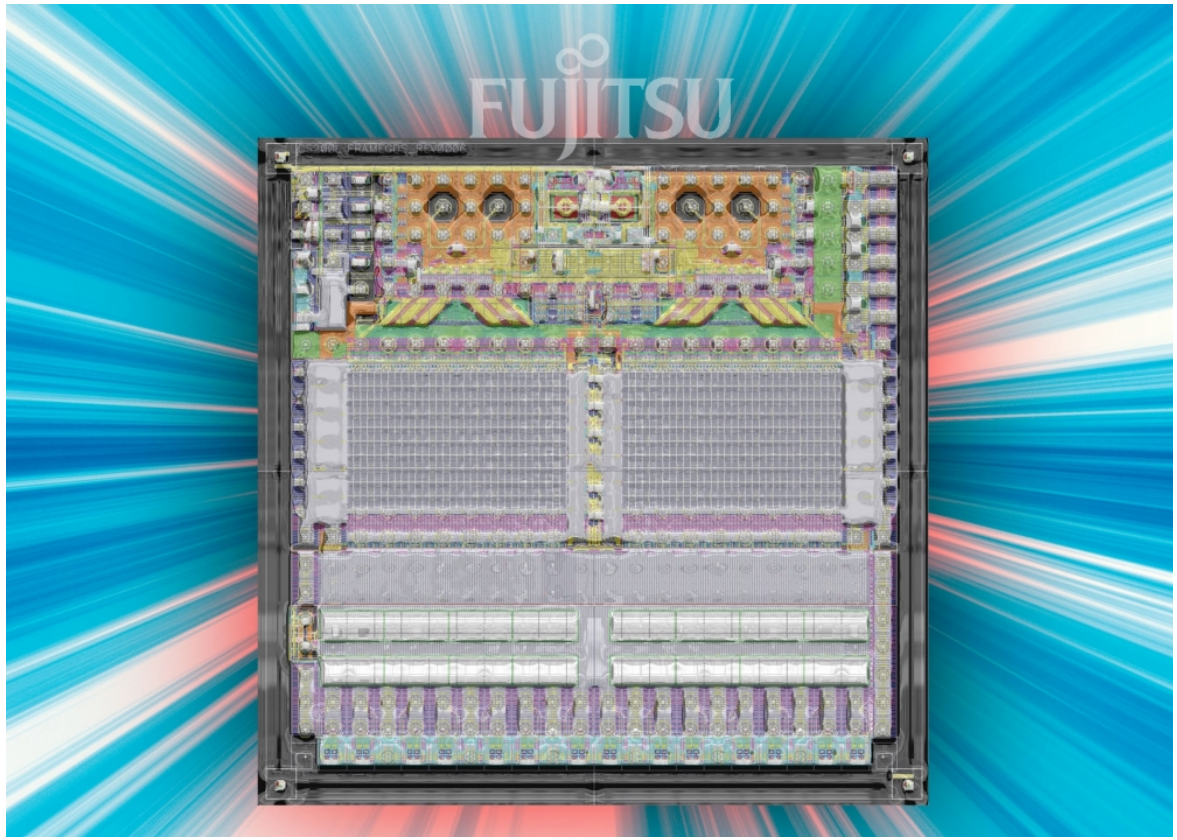


2.5 GHz instantaneous bandwidth

2009/04/22

FFTS :: *An Outlook*

Goal: Sample the whole ALMA IF-bandwidth (4 – 12 GHz)



FUJITSU‘s 56 GS/s 8-bit ADC, analog input bandwidth (-3 dB): > 15 GHz
(http://chais.info)

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MPIfR FFTS :: *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 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.

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FFTS :: *Contact, Distribution*

Contact:

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:

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Radiometer Physics GmbH

http://www.radiometer-physics.de

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