New generation of robust receivers

at

Nançay Radioastronomy Observatory

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Summary

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« Reconquête »
Multi purpose robust receiver

The Reconquete Machine as two main objectives

❑ **High dynamic range** powerful system for **spectropolarimetry measurements**
Wide band, high resolution;
Real time and quasi real time **interference excision**

❑ The « Reconquete » machine is used for **astronomical observations** and **interference identification**.
It has to be **fully configurable** and shared between three radiotelescopes

- Nançay Decameter Array
- Nançay Decimeter Radiotélescope
- Interference Monitoring Antenna

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Site and radiotelescope description (1)

Nançay Decameter Array

The ***Nançay Decameter Array*** consists in two filled aperture, phased antenna sub-arrays (made of 72 conical helix antennas each) in opposite senses of circular polarisation.

The main telescope and receiving system characteristics are:

- ❑instantaneous bandwidth : one octave
- ❑antenna gain: 26 dB in each polarisation
- ❑maximum effective aperture (at 25 MHz): 2 x 4000 m^2
- ❑declination coverage: $-20 < \delta < 50$ °
- ❑tracking time ± 4hr from meridian transit
- ❑computer controlled pointing and calibration system
- ❑set of high resolution, wide band spectrum analysers:
  - •swept frequency: 10-40 Mhz ψ 20-80 MHz , 1 sec time resolution.
  - •AOS: 2 x 12 MHz or 1 x 24 MHz bandwidth, 35 KHz frequency resolution, 3 ms time resolution.
  - •DSP polarimeter: >65 dB dynamic range, 2 x 12.5 MHz bandwidth
- ❑remote observing capability (through Internet)
- ❑avaibility from the web of digital observations quicklook data base (ψ and) since 1990

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Site and radiotelescope description (2)

Nançay radiotelescope

Main radiotelescope characteristics:

- ❑200 x 35 meters aperture
- ❑Sky coverage of 83%, down to the declination of $\delta = -39°$
- ❑Tracking time of 1h ($\delta = 0°$)
- ❑**New optimized focal system**
  - •2 shaped reflectors (double gregorian system)
  - •2 corrugated horns
    - ❑1.1 → 1.8 GHz
    - ❑1.7 → 3.5 GHz
- ❑Receivers
  - •ρ = 1.4 °K / Jy at 1.4 GHz
  - •Tsys = 35 °K at 1.4 GHz
- ❑Backends
  - •3 bits, 8192 channels, 50 MHz autocorrelator
  - •Dedicated coherent dispersor (pulsar timing)

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Site and radiotelescope description (3)

Interference monitoring antenna

Band 1

100 – 1000 MHz
Log periodic antenna 8 dBi gain
Low noise amplifiers
Spectrum analyser
Filter bank (151; 525; 163,9; 325,3; 408,5; 205; 300; 395 MHz)

Band 2

1000 – 3500 MHz
1,510 m antenna fully steerable
Beamdwidth 9.6° at 1.4 GHz, 4.5° at 3.3 GHz
Low noise amplifiers
Spectrum analyzer

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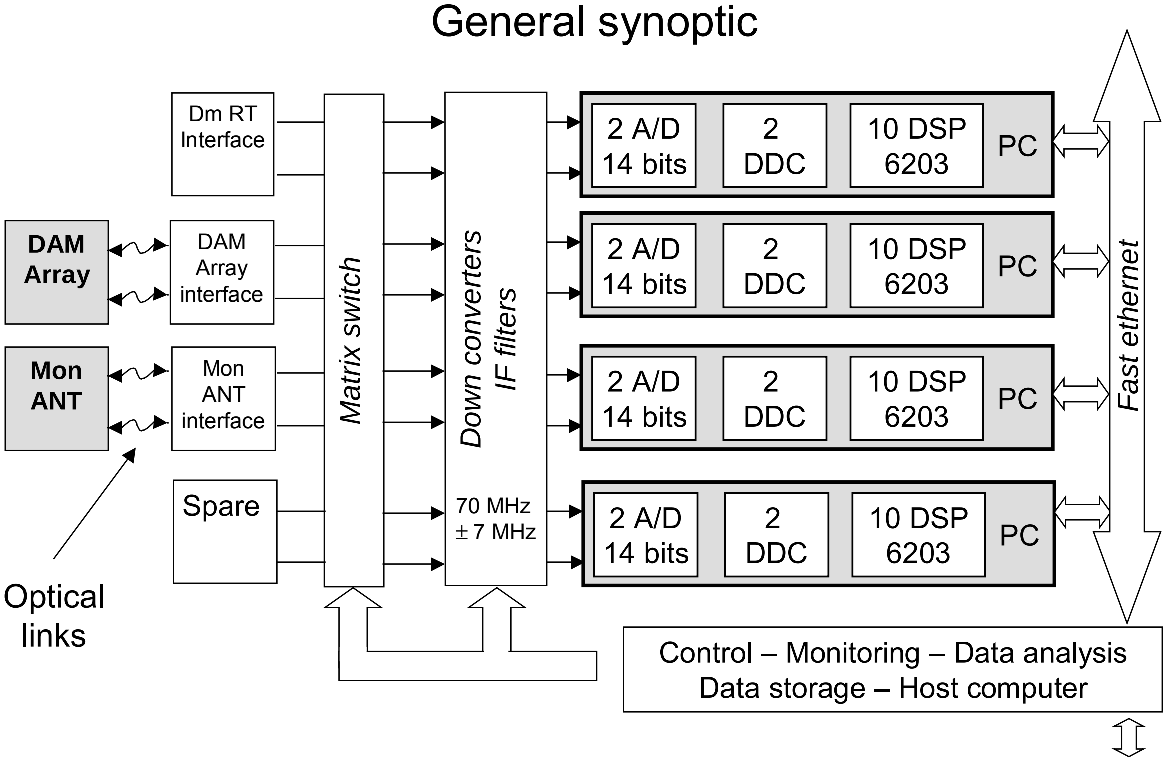
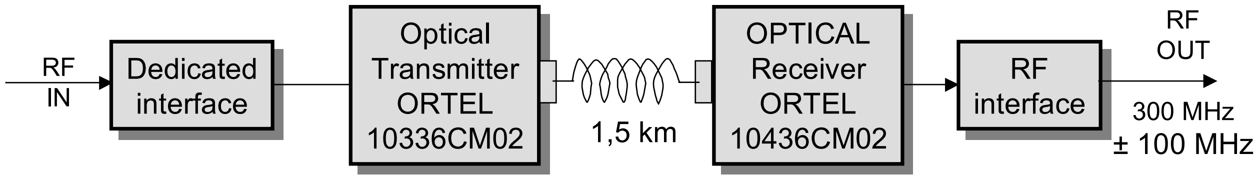
General synoptic



Optical fibers analog links

are used to send analog signals to Reconquete Machine from DAM array and interference antenna



Main characteristics are:

- ❑High dynamic range
- ❑Single mode fiber pigtail (1,3 to 1,5 nm)
- ❑10 – 1000 MHz frequency response
- ❑± 1 dB flatness

❑**Receiver** + 14 dBm compression point
+ 27 dBm 3 order intercept

❑**Transmitter** + 13 dBm compression point
75 dB output carrier to noise (30 KHz BW)
70 dB output carrier to intermode (2 sig. – 3 dBm)

❑**Comment: dynamic range is verry critical for low frequency bands and has to be improved !**

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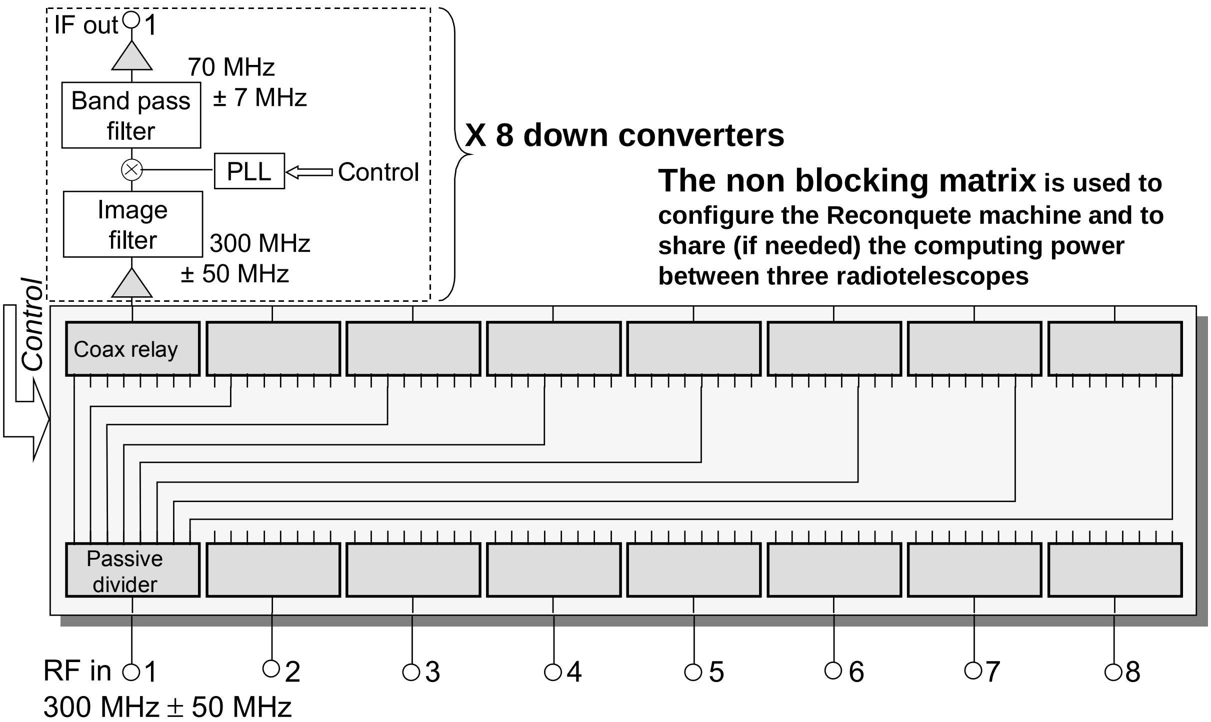
Matrix configuration and down converters



The non blocking matrix is used to configure the Reconquete machine and to share (if needed) the computing power between three radiotelescopes

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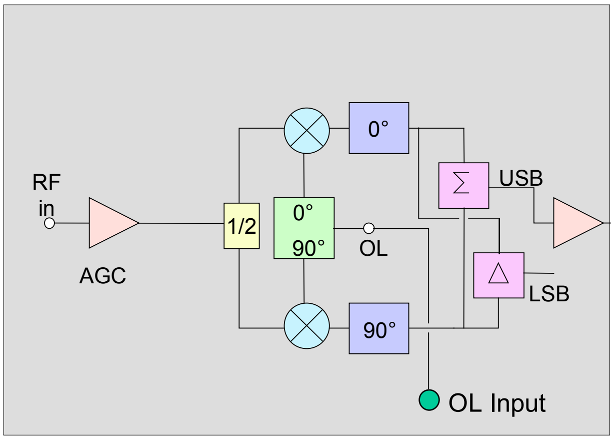
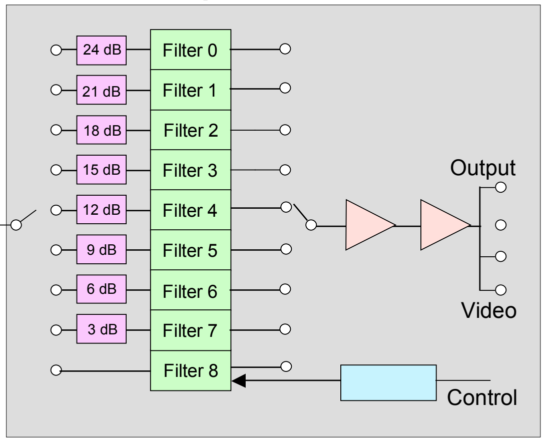
Baseband (video) conversion (1)

Single Side Band Mixer

The video down conversion is a critical part of a receiver regarding the dynamic range, image rejection, flexibility etc … The most used technic, in radioastronomy, is a single side band conversion

Image rejection mixer **Low pass filters**





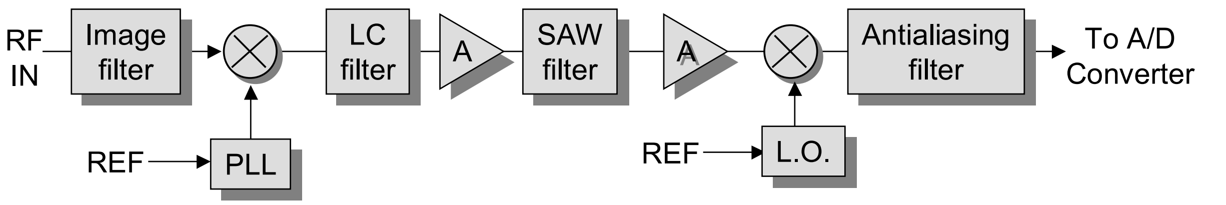
Drawbacks

- ❑Very critical analog electronics
- ❑Phase and amplitude matching difficulties
- ❑**Dynamic range limited to 25 / 30 dB max.**
- ❑**High cost**

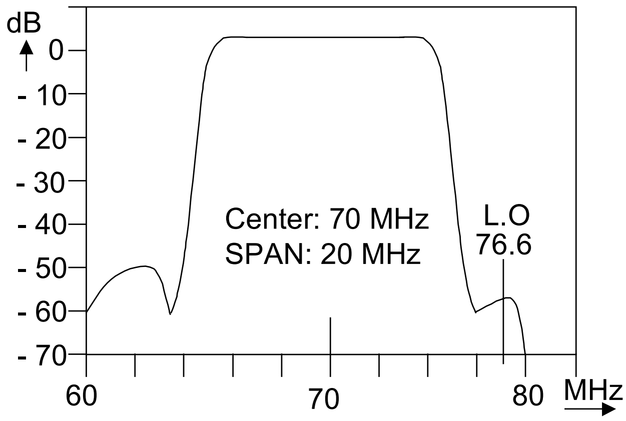
Baseband (video) conversion (2)

SAW filter method

This method is used for the two prototypes of digital receivers built in 1996 and 2000



Typical results of the association of
LC and SAW filter at 70 MHz IF (BW 10 MHz)

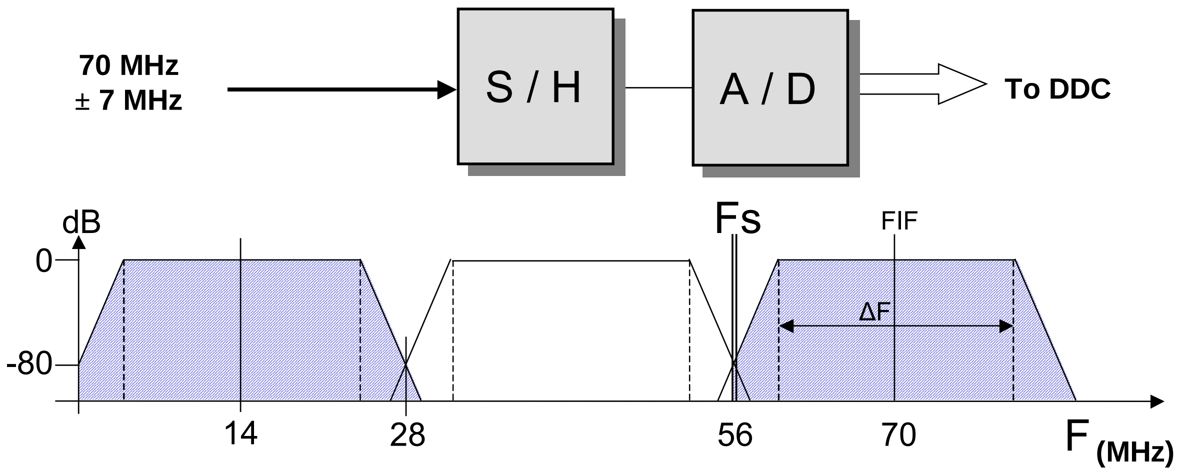


Main characteristics are:

- ❑Good dynamic range > 60 dB
- ❑Fixed bandwidth
- ❑Temperature sensitive ($LiNbO_3$ substrate)
- ❑Amplitude and phase calibration needed
- ❑High cost

Sub Sampling (video) conversion (3)

This technics is implemented in a FPGA in the digital bords of Reconquete Machine



Conditions

$$Ta = \frac{1}{2 n_B \pi F if}$$

$Fs \geq 2\Delta F$

$$Fs = \frac{4 Fif}{2n+1}$$

n_B = number of bits
Ta = aperture error time S/H
Fif = IF frequency
Fs = sampling frequency
ΔF = bandwidth

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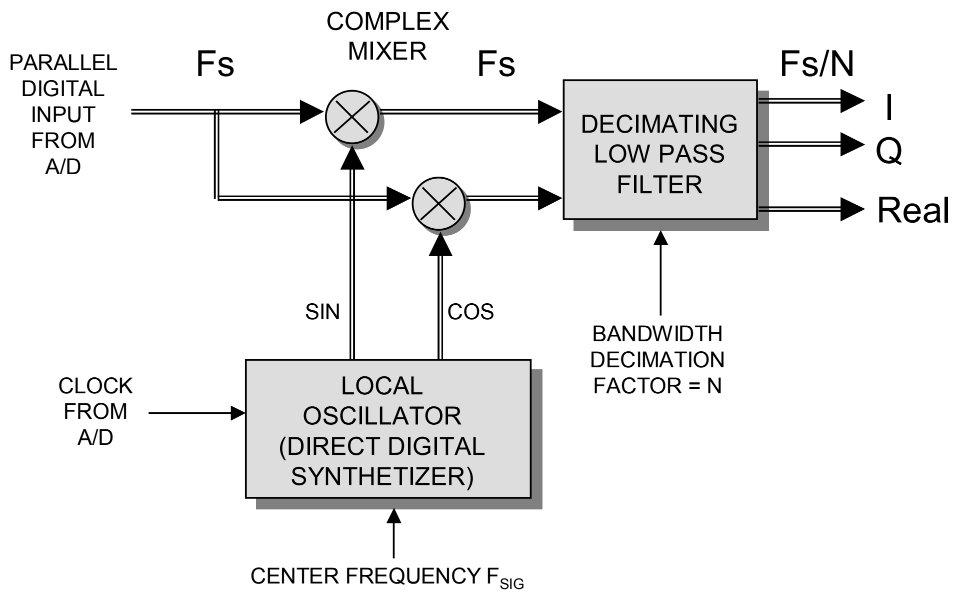
Direct Digital Converter

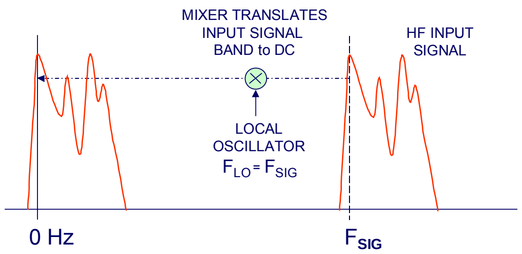


Direct Digital Converter

The direct digital converter includes a direct digital synthetiser, a complex mixer to translate the band to DC and a decimating desired filter to set the derived badwidth

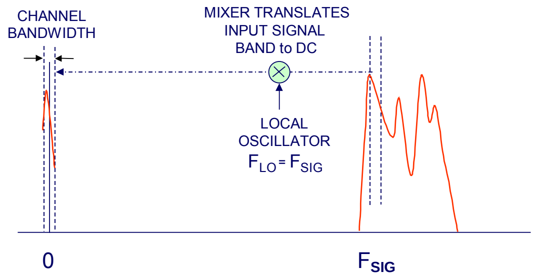
Complex Mixer Translation

Mixer translates input directly to 0 Hz or DC
(instead of IF in an analog receiver)



Decimating Filter Bandlimiting

Low Pass Filter bandwidth is set to match desired bandwidth of received channel



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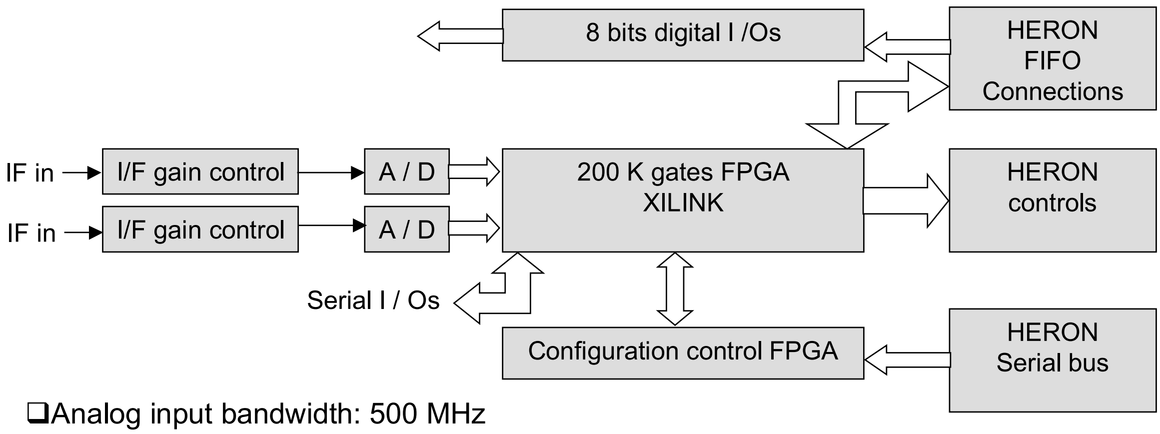
Subsampling and DDC implementation

Prototype version

Two A / D converters and two DDC (implemented into an FPGA) are contained in one HERON 1 IO1 module (hunt engineering) fitted into a PC carrier board (HEPC 9)



- ❑Analog input bandwidth: 500 MHz
- ❑A / D 105 MHz 12 bits (prototype version)
- ❑FPGA clock speed= 180 MHz
- ❑I / O bandwidth (HEPC9 carrier board)= 400 Mbytes / sec.

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Digital processing

For two sub bands (14 MHz) the digital signal processing is based on 3 PCI carrier boards (HEPC 9 from HUNT engeneering) supporting each four HERON module and one communication module.

• The First modules includes one 14 bits A/D converter and an FPGA circuit in wich the DDC is implemented.
• Four modules have an FPGA circuit supporting the FFT (or correlation) fonction
• The six remaining modules are based on TMS 6203 DSP providing about 24 GFLOPS of computing power.

One powerfull industrial PC is used for 3 carrier boards.
The four PC are linked via a fast Ethernet line to a central computer for further data analysis, compression and storage.

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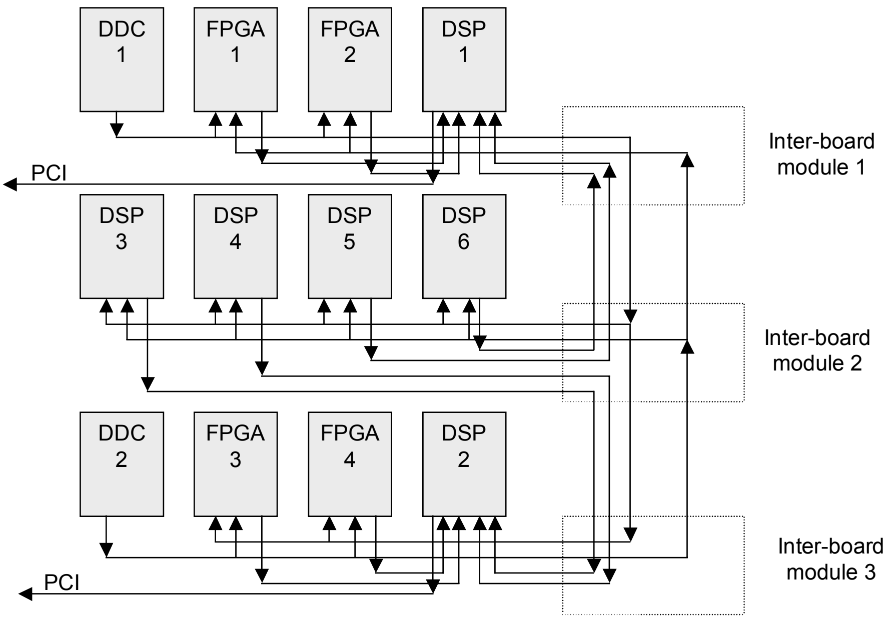
Links and connection to PCI Bus of three HEP9 carrier boards supported by a PC machine



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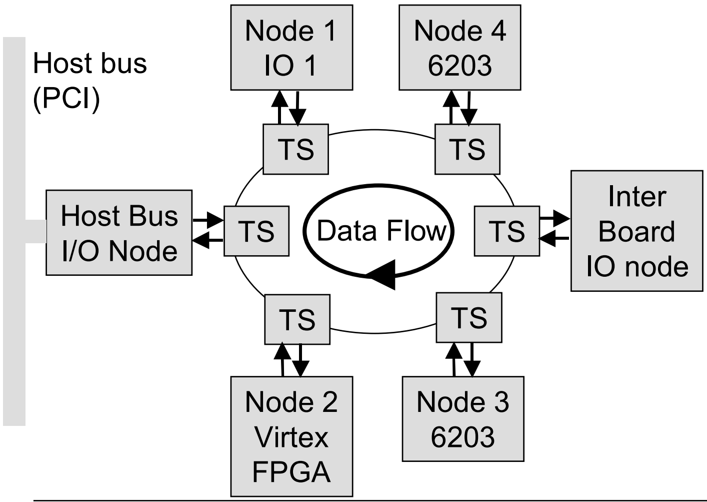
Digital processing (final configuration)

Carrier board and Heart architecture

A PCI carrier board (HEPC9) supports 4 Heron modules and one communication Module for inter board connection.



NODE 1	A/D + DDC (FPGA) Fifo at 400 MB/s (Heron 4)
NODE 2	VIRTEX FPGA
NODE 3, 4	TMS 6203 (Heron 2) 2 MB of flash ROM and 32 MB of SDRAM FIFO of 400 MB/s

HEART ring splitted into 6 times slots
66 Mbytes bandwidth

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Post detection digital signal processing

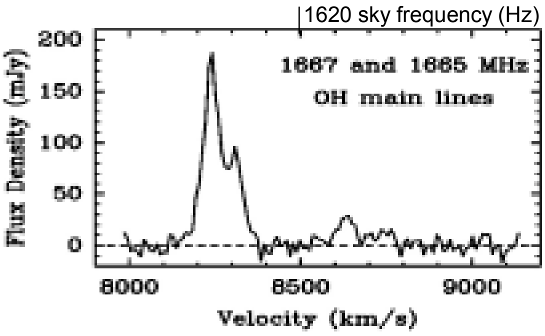
Several algorithms are used at Nançay for post detection RFI excision according each astronomical observation. But no systematic software is implemented.

- ❑White noise hypothesis ($1/\sqrt{b\sigma}$ analysis)
- ❑Adaptative filtering (pulsar observations)
- ❑Polarisation discrimination
- ❑Thresholding
  - Background determination
  - Fixed frequency RFI
  - Wide band fast RFI
  - Adaptative masks (Iridium)
- ❑…

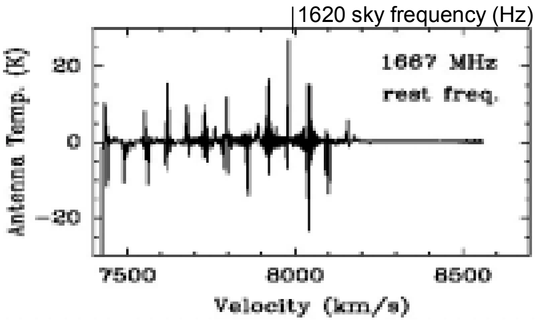
Radio astronomy outside protected band at decimetric Wavelength with Nançay radiotelescope (1)

The signal of interest is III ZW 35 IRAS, clearly visible in 1987 and impossible to see at present time due to the presence of strongs Iridium emissions.

Signal of interest:
III ZW 35 IRAS
As seen in 1987, before Iridium



Now a days: 16 mn On – 16 mn Off results
With NRT's DAC
In the Iridium band



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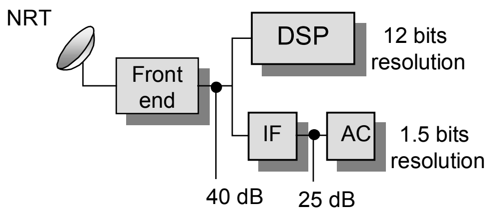
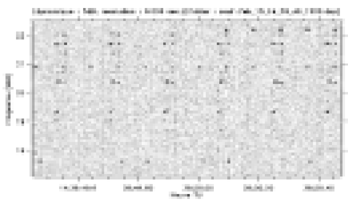
Radio astronomy outside protected band at decimetric Wavelength with Nançay radiotelescope (2)

Description of measurements
with DSP receiver

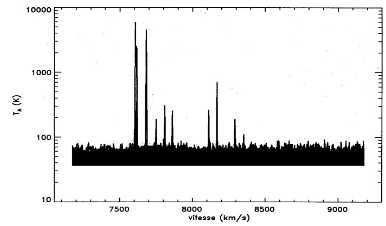


The signal was stored and an excision algorithm was applied using a Time-Frequency masking whith adaptive mask of 90 ms calculated over 5 seconds of signal.

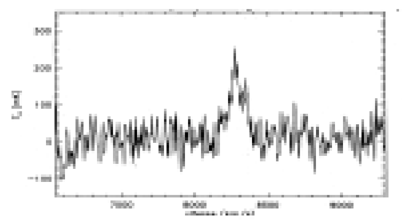
Each power peak ouside 2 sigmas of the stastical variation is taged in the mask pattern and wont be considered when integrating



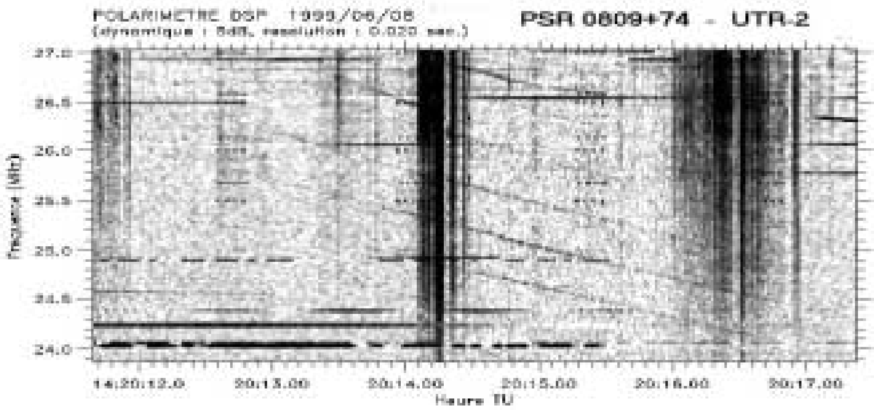
Raw spectra, after correction of the
receiver spectral response at 12 ms resolution
shows that Iridium is 10 000 stronger than the sky noise level



Results: IIIZW35 integration : 960 s ON – 960 s OFF
80% of acquisition efficiency
45 minutes of post processing on a 450MHz Pentium II



example of detection, in the decameter band of pulsar emission at UTR2 ukrainian Radiotelescope.
High dynamic range of digital receiver is needed due to the very strong broadcast emitters



Real time detection of dispersed pulses of the pulsar PSR 0809+74
in presence of strong RFI with DSP receiver at UTR-2 decameter radiotelescope.
(Lecacheux, Konovalenko et al.)

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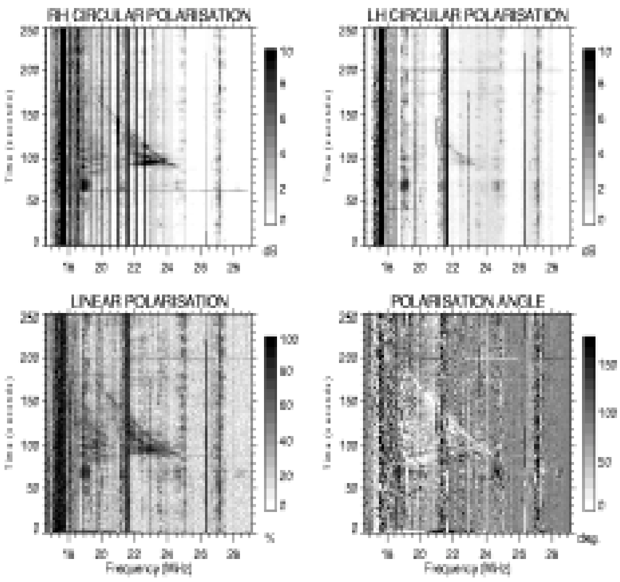

Example of observation of radio emission from Jupiter magnetosphere at decameter frequency range using high dynamic range spectropolarimeter

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Conclusion

- **Today, very high dynamic range (60 to 80 dB) is needed**
- **in order to avoid non linear effects**

- **Solutions are available for backends, but the cost has to be decreased.**

- **Improvements in dynamic range and filtering are needed for frontends in cool and warm electronics**

- **Post detection digital signal processing for RFI excision has to be improved in order to reduce the data storage.**