INTERNAL REPORT

VLBI observations with the Sardinia Radio Telescope: Hardware & Software implementation

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The Very Long Baseline Interferometry (VLBI) is a technique of astronomical interferometry used in radio astronomy.
One of the most sensitive VLBI array in the world is the European VLBI Network (EVN): Medicina and Noto Italian radio-telescopes are already partners of it and SRT will join very soon.
In this report an overview of the entire infrastructure used to conduct VLBI observation is presented.
We will focus on our hardware and software implementation and, finally, will show the results achieved.

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1 Introduction

SRT has recently started some preliminary EVN observation test, although in shared risk. Several tests (using the L-band, C-band, K-band receivers) have been done successfully during 2014, and excellent fringes were achieved.
In this report we will describe the entire infrastructure that we will use for VLBI observations at the SRT.
Chapter 2 and 3 describe each detail about the hardware and software implementation.
Finally, the first correlation results are illustrated in chapter 4.

2 Hardware Implementation

The SRT VLBI hardware at SRT is made up by the following major parts: a *DBBC+Fila10G*, a *Mark5C* recording system and a router that operates as a SFP+ → CX4 converter.
A brief description of the aforementioned parts will be done in the next paragraphs.

2.1 Digital Base Band Converter

The Digital Base Band Converter (DBBC) [1] is the new digital platform developed by Hat-Lab (an INAF spin-off company) that gradually is replacing the old analog terminals of the European VLBI Network. It is based on a programmable logic, so that it can be used for other purposes too [2].

The DBBC can process up to four intermediate signals simultaneously. First of all a signal conditioning is necessary for these signals: four conditioning modules (see fig. 1) are needed to achieve this.

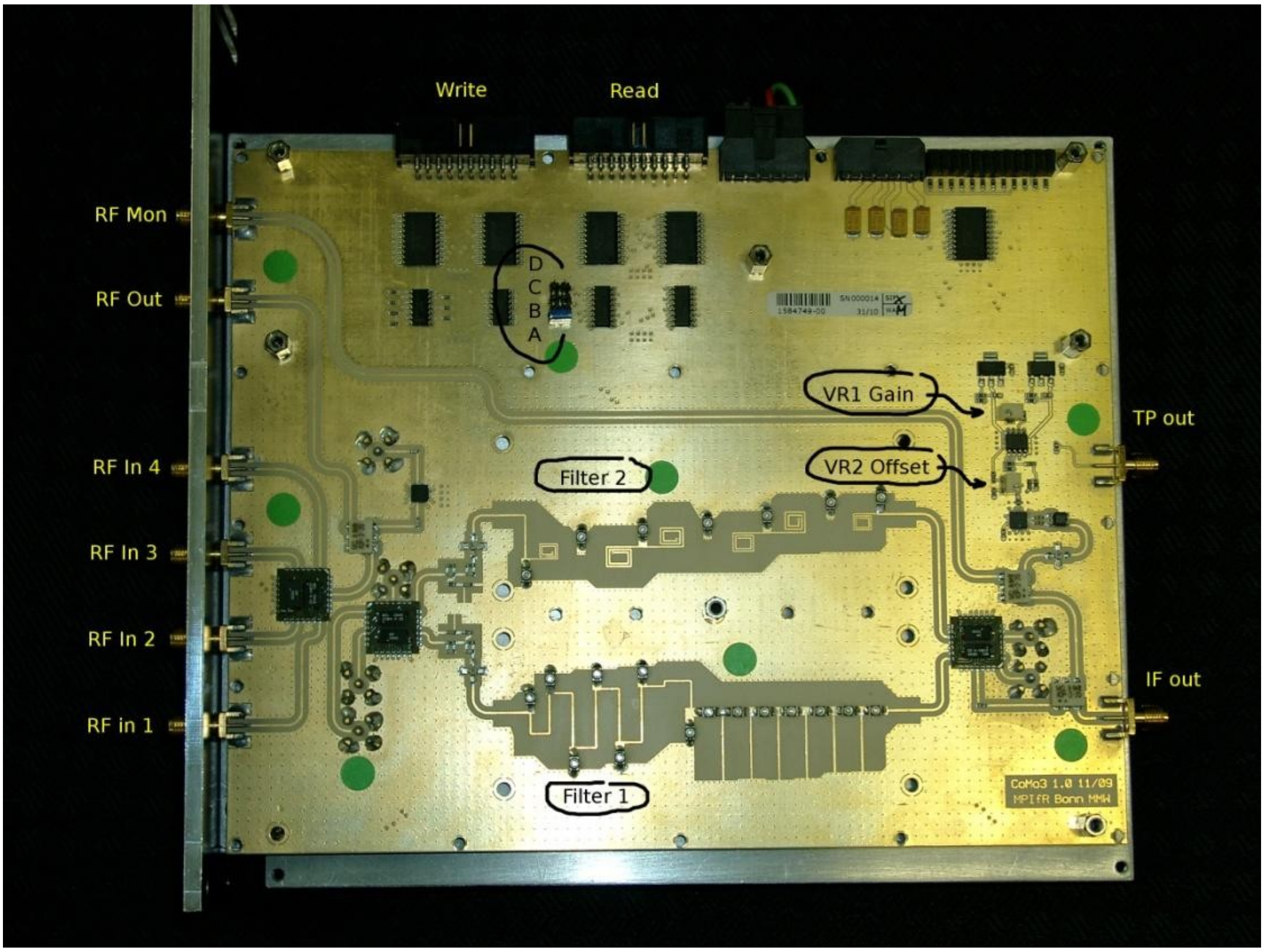


Figure 1: One of the four conditioning module

Each conditioning module accepts four intermediate frequency signals (RF In 1, RF In 2, RF In 3, RF In 4), just one at once can be however processed. Once the signal to analyze has been selected, two copies of it are available: the first one (RF Mon) is the signal conditioned, and the second one (RF Out) is the no-conditioned input; there is also an automatic or manual gain control.
Two anti-aliasing filters (10-512 MHz and 512-1024 MHz) enable us to operate in the first or in the second Nyquist window respectively, and eventually the total power full band is calculated (TP out).

The four conditioned signals are sent (IF out) to the related analog-to-digital converters (ADB2, see figure 2).

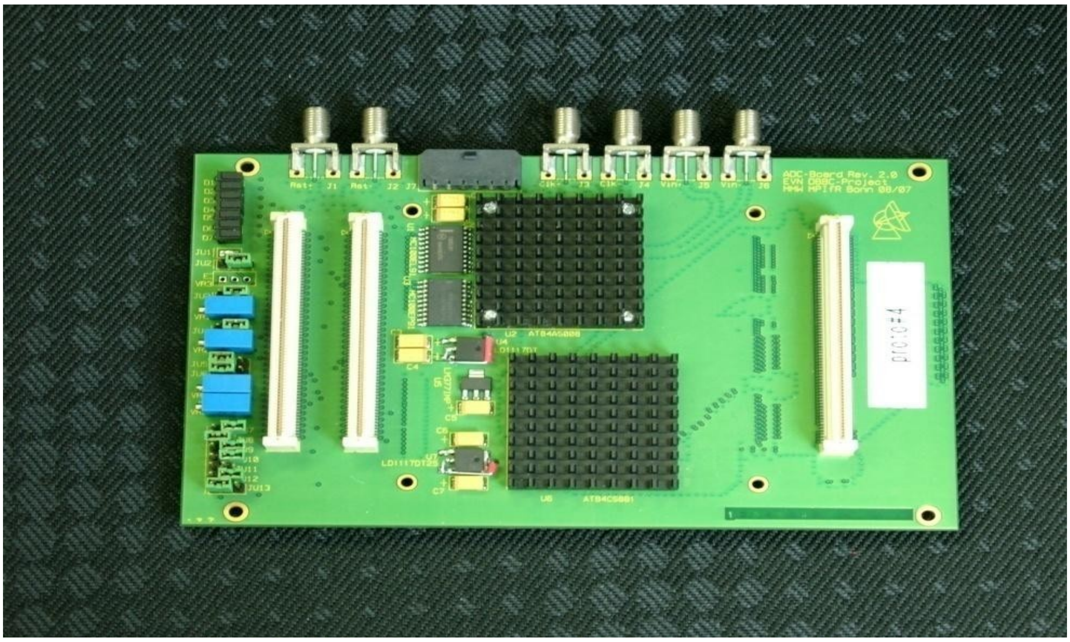


Figure 2: ADB2 board

Even if two different sampling frequency (1024 MS/s and 2048 MS/s respectively, 8-bit representation) are supported, just one is concretely used for VLBI, allowing a 512 MHz maximum instantaneous bandwidth for each of the four IFs.

Once the data are in digital format, four digital boards (CORE2, see figure 3), based on a Xilinx Virtex 5 XC5VLX220 FPGA process them.

In order to control the stack of the four ADB2-CORE2 couples, two boards called FILA (First-Last, see fig. 4) are placed up stream and down stream.

The data processed by the stack are thus sent to the Fila10G board (see fig. 5), via flat cables, exploiting the two VSI output connectors contained in the FILA board.

Finally, the data are packetized into the Fila10G according to the VDIF (VLBI Data Interchange Format) [3] and sent via optical fibers to the SFP+ → CX4 converter described in chapter 2.3.

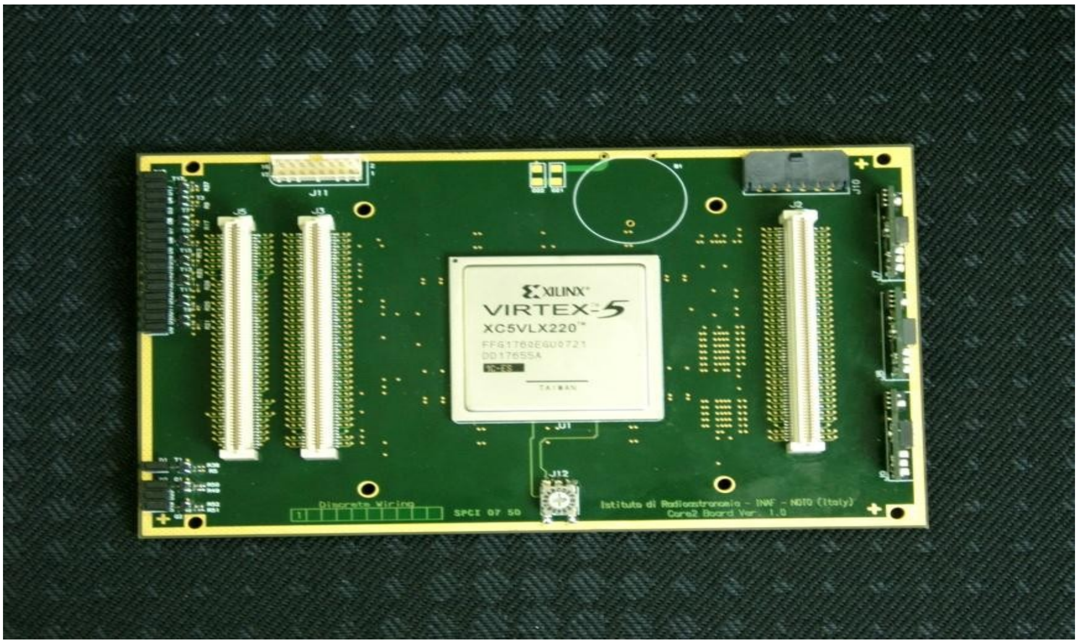


Figure 3: CORE2 board

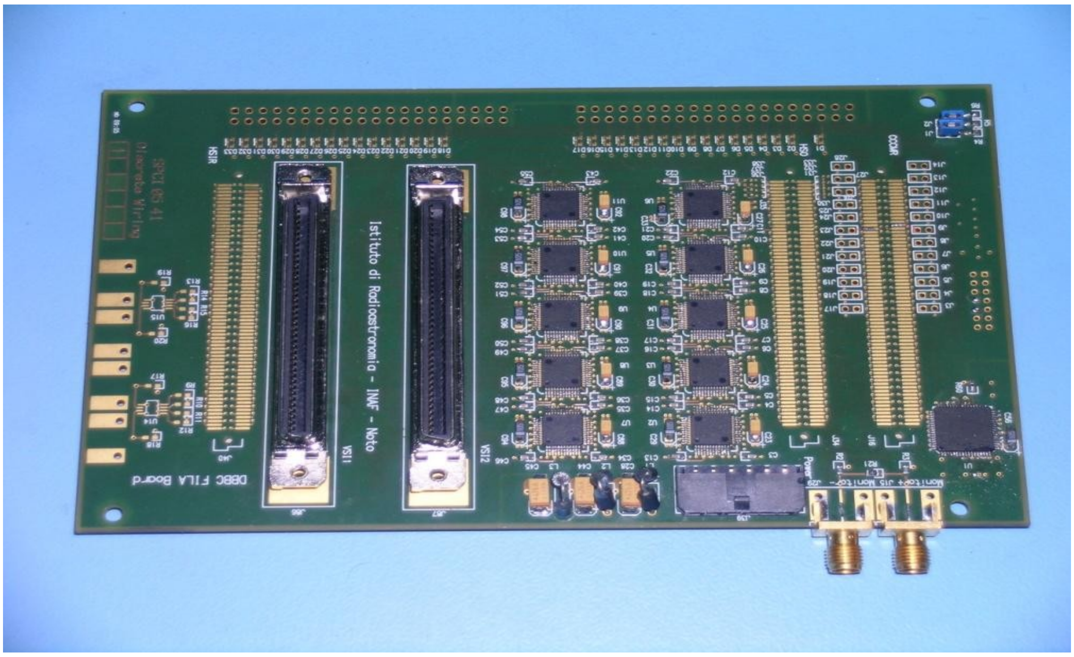


Figure 4: FILA board

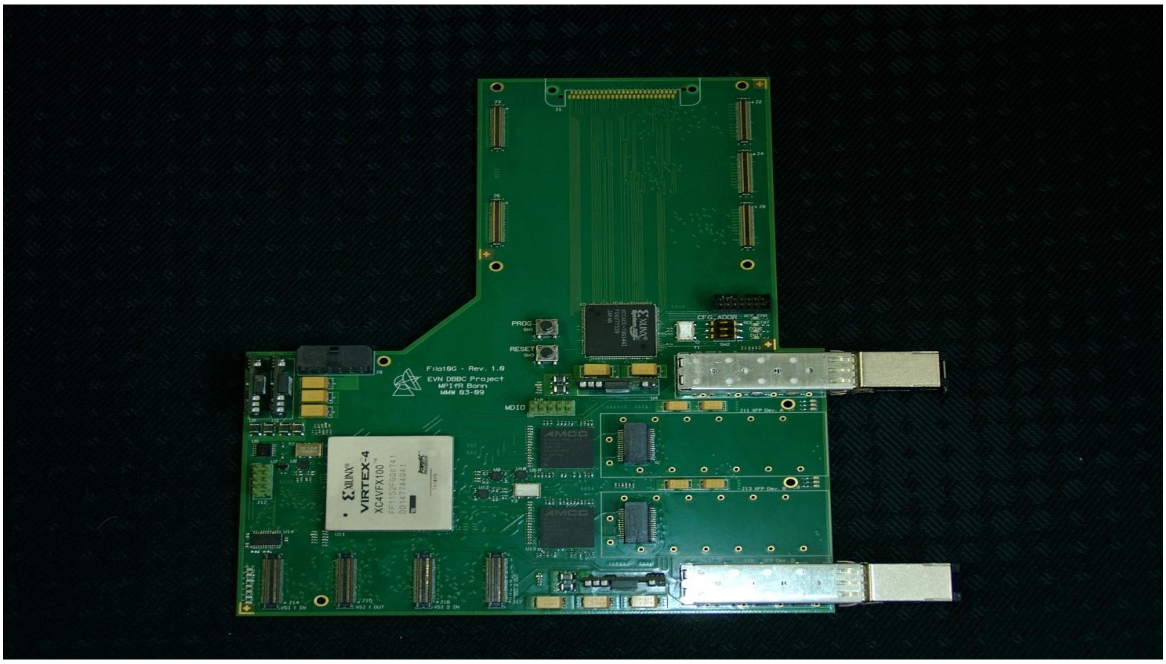


Figure 5: Fila10G board

2.2 Mark5B+ and Mark5C

The Mark 5 system was developed at Haystack Observatory as the first high-data-rate VLBI data system based on magnetic-disk technology. Incorporating primarily low-cost PC-based components, the Mark 5 system supports data rates up to 2048 Mbps, recording to an array of 8 inexpensive removable ATA disks.

The Mark 5B+ is a VSI-H compliant system with recording capability extended to 2048 Mbps.

The Mark5C is a system with the capability to support up to 4096 Mbps from a 10 Gigabit Ethernet data source; playback, as well, is via a 10 Gigabit Ethernet data stream, which is compatible with software correlators.

The Mark 5C is fundamentally a ‘formatless’ packet recorder, though a parallel Mark 5C data-format specification defines a suggested standard VLBI data format; it can also be configured to write data to disk in a Mark 5B-compatible data format that allows playback on standard Mark 5B/5B+ systems.

Figure 6 shows the system DBBC-Mark5C at the SRT apparatus box:

Figure 6: DBBC & Mark5C at the Sardinia Radio Telescope apparatus box

2.3 Network setup and connections

The network equipment for VLBI at SRT is a VLAN virtual switch, whose configuration runs into the SRT core Brocade Big Iron RX8 device. The RX8 chassis hosts hot swappable modular network cards (1GbE copper RJ45 standard ports and optical SFP+, 10GbE optical XFP, and CX4-XFP transceivers), management cards and redundant power supply.

The Big Iron VLBI dedicated card RX-BI-4XG has 4 x 10 GbE optical ports and hosts:

• two 10G-XFP-SR transceiver modules

• one 10G-XFP-LR transceiver module

• one 10G-XFP-CX4 transceiver module

The current SRT VLBI equipment connects to the network card 4 of the BigIron VLBI:

• the mark5c-CX4 port to the CX4 transceiver (ethernet port 4/4);

• the eth0 port of Fila10G to the 10G-XFP-SR transceiver (ethernet port 4/2).

The next image shows the Network card 10 GB ports and CX4, XFP Long Range (blue) and XFP Short Range (white) optical transceivers:

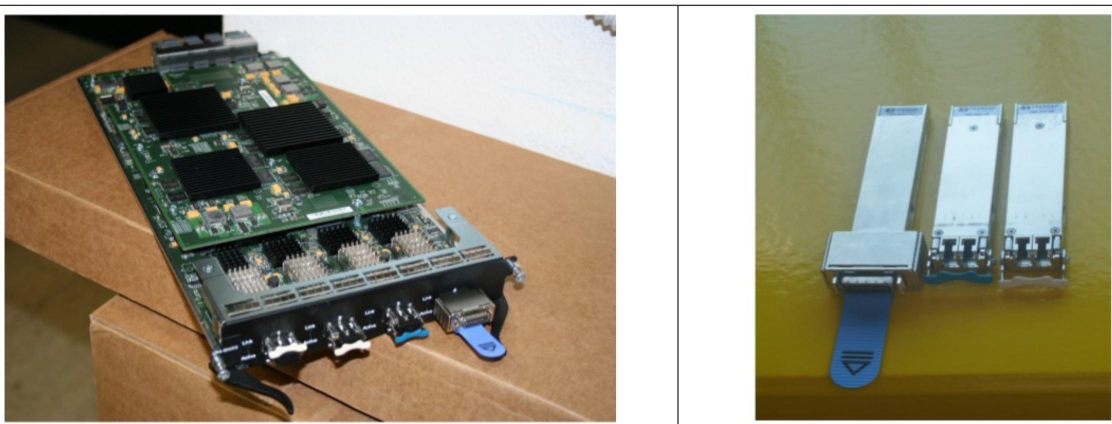


Figure 7: Network card 10 GB ports and CX4, XFP Long Range and XFP Short Range optical transceivers

The future SRT-VLBI expansions will connect:

• Fila10G eth1 port - 10G-XFP-SR tranceiver module (ethernet port 4/1)

• WAN *X*-GbE backbone router - 10G-XFP-LR tranceiver module (ethernet port 4/3)

The complete network scheme will be like the one shown in the next figure:

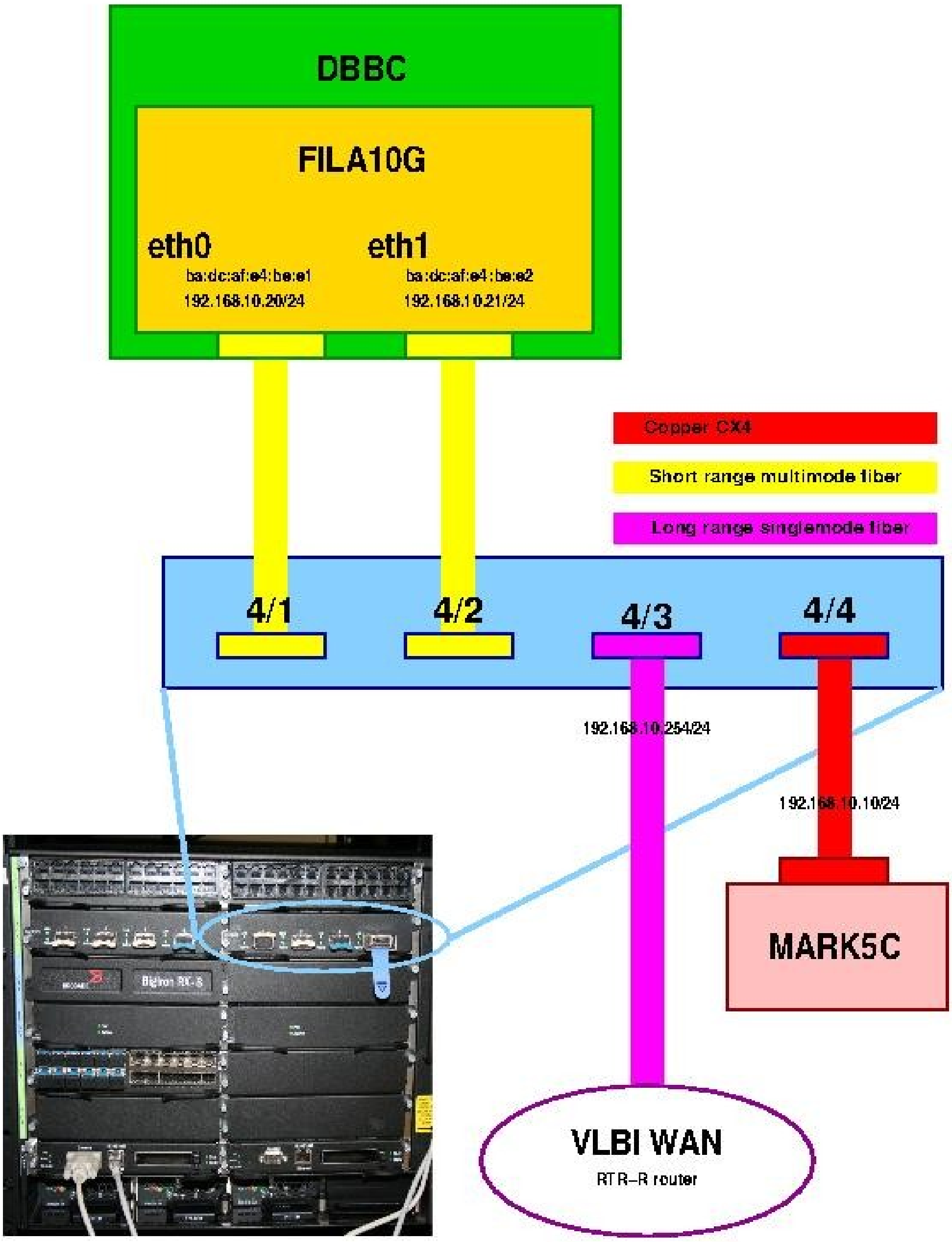


Figure 8: Complete network scheme

The network configuration parameters are listed in the Fila10G configuration file, for both eth0 and eth1 ports, mark5c and destination gateway(s). Our VLBI network is the C private class 192.168.10.0/24 being nm=24 the netmask value in CIDR notation.

The first section is referred to the Fila10G eth0 and eth1 network ports parameters, sending data streams to the WAN network across the gateway 192.168.10.254

```
echo ---- Source MAC, IP, Port for eth0

echo tengbcfg eth0 mac=ba:dc:af:e4:be:e1 | sendstr %F10GCOM%

echo tengbcfg eth0 ip=192.168.10.20 gateway=192.168.10.254 nm=24 | sendstr %F10GCOM%

echo tengbcfg eth0 port=46227 | sendstr %F10GCOM%

echo ---- Source MAC, IP, Port for eth01

echo tengbcfg eth1 mac=ba:dc:af:e4:be:e2 | send sending str %F10GCOM%

echo tengbcfg eth1 ip=192.168.10.21 gateway=192.168.10.254 nm=24 | sendstr %F10GCOM%

echo tengbcfg eth1 port=46227 | sendstr %F10GCOM%
```

The latter section is referred to the mark5c data recorder address. In our configuration the mark5c IP is 192.168.10.10, which must also be translated in a hexadecimal notation (192.168.10.10 CIDR = C0A80A0A HEX).

```
echo -- Setting destination IP address 192.168.10.10 for eth0

echo regwrite regbank0 11 0xC0A80A0A | sendstr %F10GCOM%

echo – Setting destination IP address 192.168.10.10 for eth1

echo regwrite regbank0 6  0xC0A80A0A | sendstr %F10GCOM%
```

The last section reports the destination mac address for the optical gateway and the mark5c device. The first one is the mac address of the recording device remote destination. The second one is referred to the mark5c, that does not work as standard layer 2/3 device: in that case is necessary to assign a fake mac address to the CX4 port. In our case we used the same "fake" mac address (see next section) for both IP destinations (10 and 254), because the optical gateway for e-vlbi is not connected.

```
echo – Adding MAC for gateway (192.168.10.254) and dest IP (192.168.10.10) in eth0 ARP

echo tengbarp eth0 254 00:60:dd:47:76:e5 | sendstr %F10GCOM%

echo tengbarp eth0 10 00:60:dd:47:76:e5 | sendstr %F10GCOM%

echo – Adding MAC for gateway (192.168.10.254) and dest IP (192.168.10.10) in eth1 ARP

echo tengbarp eth1 254  00:60:dd:47:76:e5 | sendstr %F10GCOM%

echo tengbarp eth1 10 00:60:dd:47:76:e5 | sendstr %F10GCOM%
```

For our present working setup, involving only DBBC and mark5c, the relevant parameters of the Fila10G configuration file are those referred to the eth0 Fila10G port and the mark5c. The VLBI setup hosted on the SRT core switch requires a VLAN configuration. A new vlan (10) named MARK5-DBBC has been added to the default vlan (1), including untagged ports from 2 (Fila10G) to 4 (mark5c) on module card 4. The spanning tree protocol have been disabled, and the jumbo frames have been enabled. The mark5c CX4 port doesn't send broadcast arp messages to the network. To enable the ethernet traffic, between the DBBC and the mark5c, the "fake" mac address must be statically injected in the switch network arp table, and related to the CX4 transceiver (4/4 ethernet CX4 port).

The VLBI section of the SRT core switch "running config" is listed here:

```
!
vlan 10 name MARK5-DBBC
 untagged ethe 4/2 to 4/4
 router-interface ve 10
 no spanning-tree
 static-macaddress 0060.dd47.76e5 ethernet 4/4
 max-framesize 9194
..................................
interface ve 10
 ip address 192.168.10.254/24
```

3 Software Implementation

In this chapter we will show an overview of the VLBI observation software.

3.1 DBBC control software

As we said earlier, the DBBC essentially consists of a PC that controls the following major parts: a *synthesizer*, four *conditioning modules,* a *ADB2-CORE2* stack and the *Fila10G*.

The *Clock_1024.exe* file sets the synthesizer; a 1.024 MHz clock frequency is therefore generated and sent to the ADB2 boards.

So as to control and programming the conditioning modules and the ADB2-CORE2 stack, two PCI board can be used: PCI-9111 HR [4] and PCI-7200 [5] respectively. In dealing with the latter one, each low-level detail is described in a previous report [6], while the conditioning modules are controlled by the following methods: *Register_Card, cm_board_read, cm_board_write, read_channel*.

There are two main processing modes for the data in a VLBI session: Polyphase Filter Bank (PFB) and Digital Down Conversion (DDC).
The first one splits up the entire input bandwidth in smaller identical pieces base-band converted where sub-band's width cannot be varied.

The second mode consists of some digital receivers each one composed by a mixer + local oscillator (that down-converts a selected portion of the signal in baseband) and some low pass programmable digital filters with which the desired output portion of the bandwidth can be chosen.

Figure 9 and figure 10 show the two different approaches.

Actually, just the DDC mode is used; up to sixteen digital receivers are available and usable.

Firstly, the DDC server must be launched, so the conditioning modules, CORE2 and Fila10G boards will be properly configured.

Once that is done, the PC that controls the DBBC waits for external connections, in particular it will accept requests from the Field System. In the next paragraph each detail will be clearly explained. An internal client enables a manual configuration of the board's parameters. For instance we can set the IFs to send to the various ADB2 boards, the corresponding attenuation, which anti-aliasing filter we want to use and so on. Similarly, each of the 16 BBCs can be programmed by setting the initial frequency, the bandwidth etc.

The Fila10G must be properly configured and also synchronized with the 1PPS.

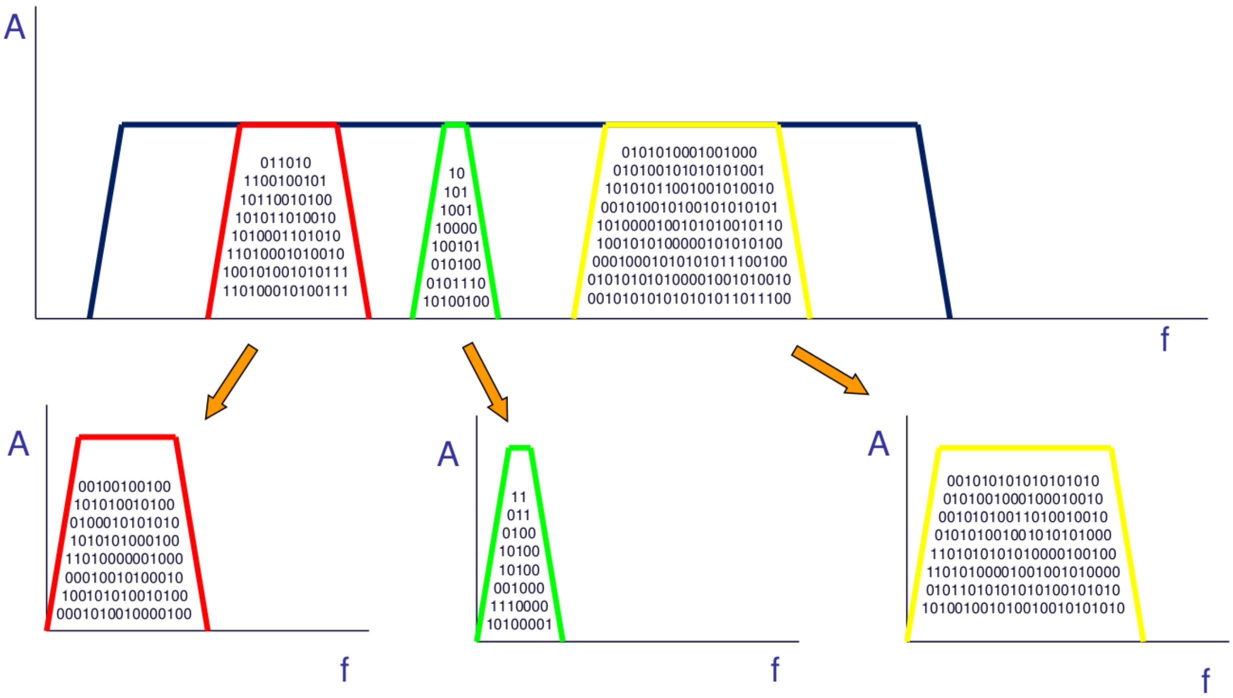


Figure 9: DDC mode

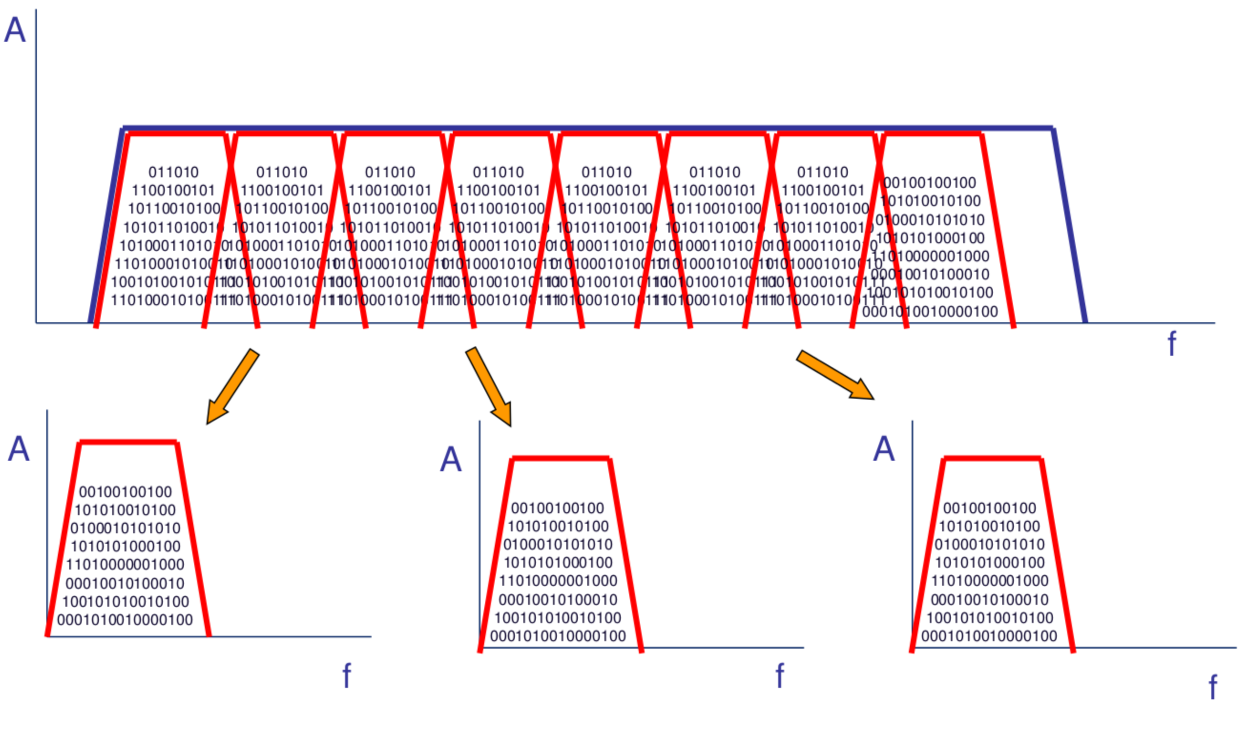


Figure 10: PFB mode

3.2 Field System

The Field System (FS) [7] is a software package that provides an interactive and automated control of the VLBI stations in order to manage the antenna pointing, the backend (DBBC) and the recording system (Mark5C/B+) management and control.

The FS provides several features that are useful for adapting or customizing it for a particular station. The most fundamental of these is that it is organized into station independent and station dependent parts. The station independent parts provide the basic support for the VLBI back-ends. The station dependent parts can be customized to support the different hardware and antenna interface that is found at a particular station.

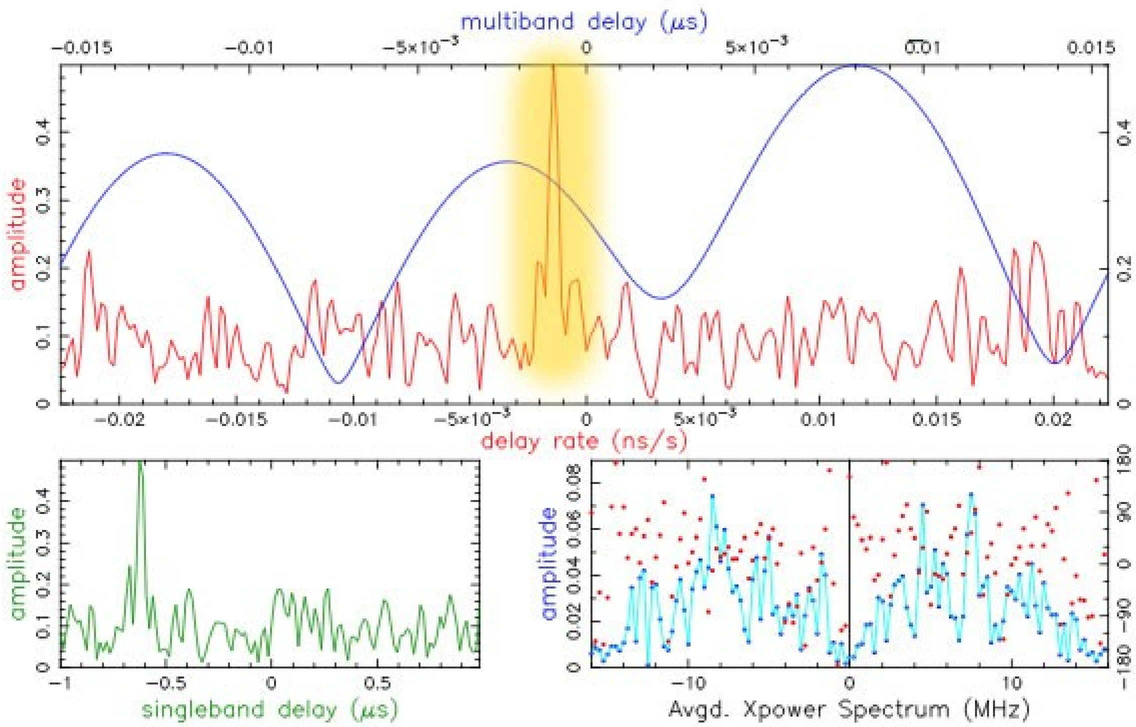
The most important part of the station dependent software is the ANTenna CoNtrol program (ANTCN). The design of the ANTCN program is such that once it is properly implemented at a station, the antenna has certain standard features from the FS's point of view. Once these features exist, the control of the antenna from a schedule and for pointing and sensitivity measurements can be carried out in a station independent fashion.

We modified this ANTCN program in such a way that we are able to point the antenna using the SRT control software NURAGHE (via a TCP/IP connection between them) and to use the FS to control the DBBC, the Mark5C, the local oscillator and the calibration mark of the receivers used during a VLBI observation.

4 First results

In this chapter we will show the first results achieved in 2014.

The Figure 11 represents the first fringe (obtained in January) that is related to a K-band (central feed) test held by Medicina and SRT:



Fiigure 11: First fringes during a test between SRT and Medicina at K band (27th of January 2014)

The fringes obtained during the first EVN tests (usually named “fringe tests” by EVN consortium) in which SRT has participated are shown in figure 12, 13, 14.

Figure 12 is regarding L-band, figure 13 the K-band whereas the figure 14 is about C-band.

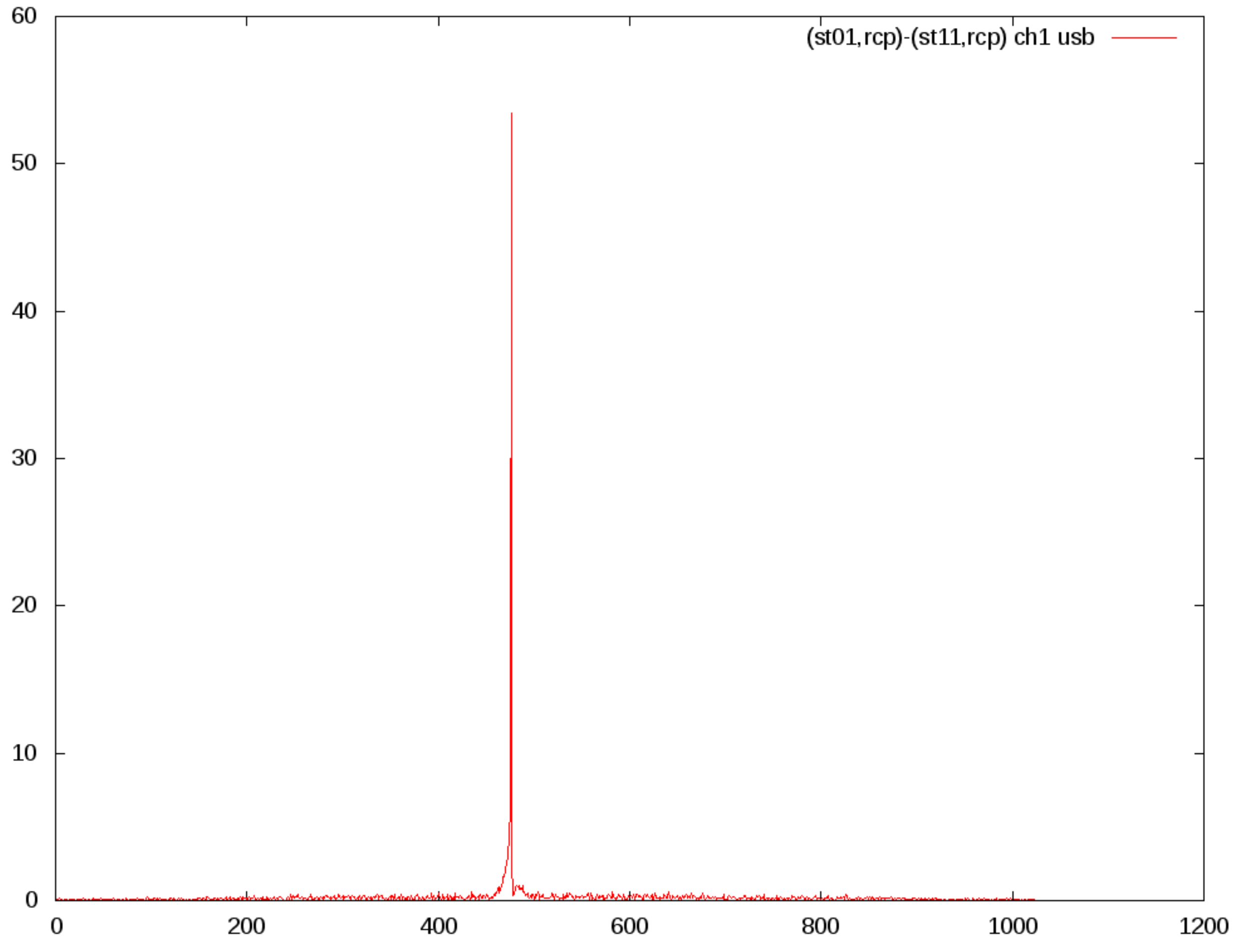


Figure 12: First fringes during the first L band EVN test (21st February 2014)

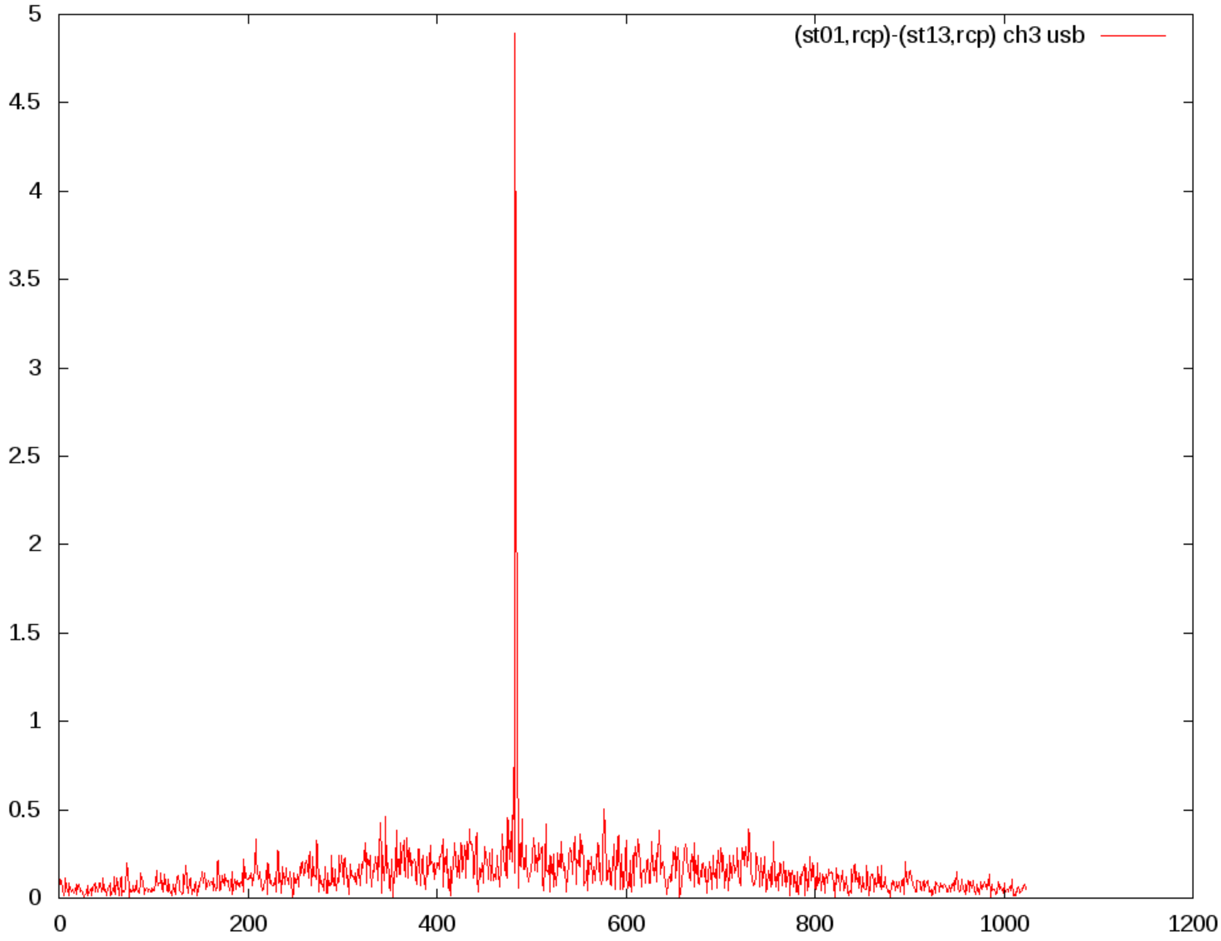


Figure 13: First fringes during a K band EVN test (3rd March 2014)

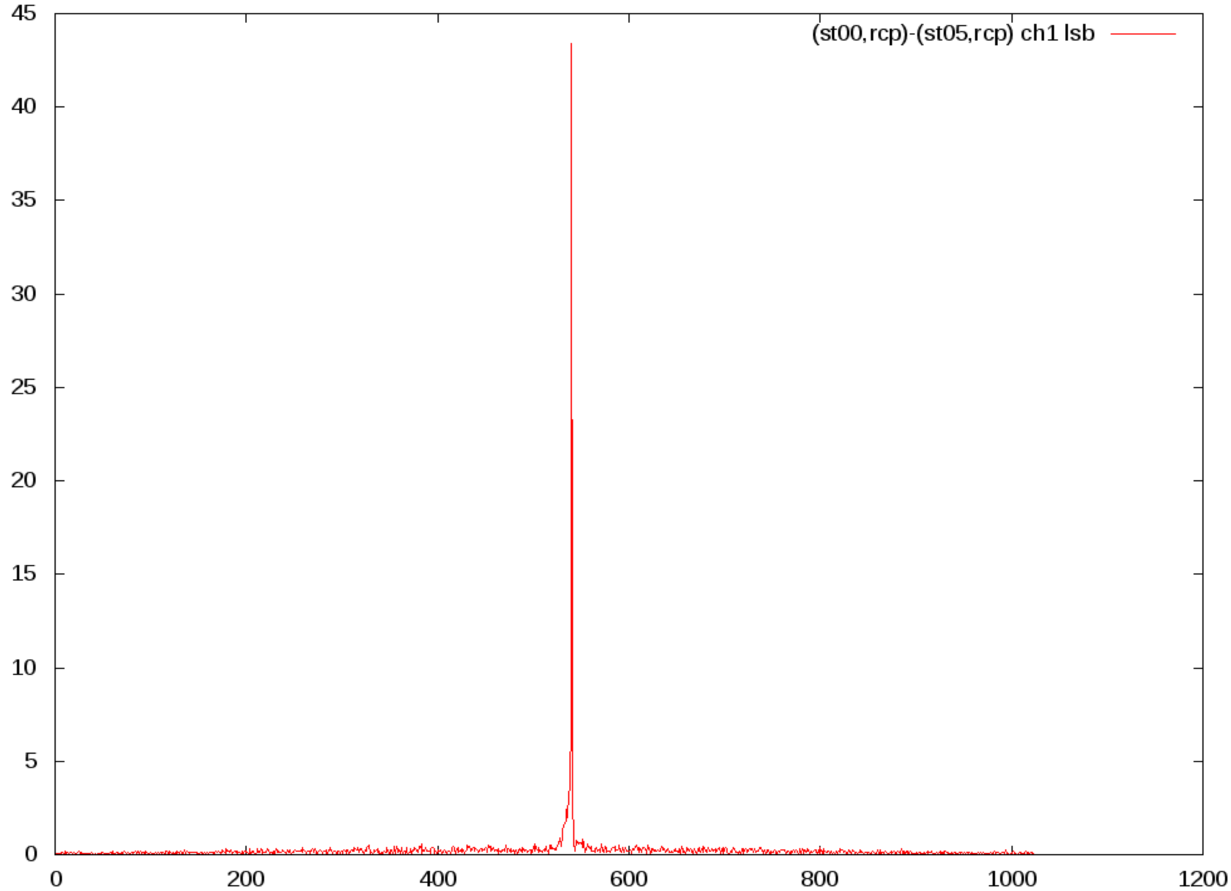


Figure 14: First fringes during a C band EVN test (12nd June 2014)

Recently (November 2014) a first Radio Astron P-band test has been done, nevertheless data have not been correlated yet.

5 Conclusions and future perspectives

In this paper, all the hardware and software needful to hold a VLBI session at the Sardinia Radio Telescope were presented. The entire infrastructure is completed and ready for the full VLBI operations, as good fringes obtained prove.

Finally, by taking a view to the future, we are planning to enhance our hardware equipment by purchasing and installing the upcoming DBBC3, Fila40G board and Mark6 recording systems.

6 References

[1] Tuccari, G. "*Dbbc – a wide band digital base band converter*" in [Third General Meeting], Vandenberg, N.R. And Bayer, K.D., eds [2004]

[2] A. Melis, R. Concu, A. Trois, C. Migoni, R. Ricci, M. Bartolini et al: "*An RFI monitoring system based on a wide- band digital back-end for the Sardinia Radio Telescope*", OAC Internal Report n.36, 2014.

[3] http://vlbi.org/vdif/

[4] http://ciclope.fi.upm.es/display/docs/manual.PCI9111.pdf

[5] http://www.acceed.com/manuals/adlink/P7200%20Manual.PDF

[6] A. Melis, G. Comoretto "*Software di controllo per il Digital Base Band Converter: Software di comunicazione con la FPGA*", Arcetri Technical Report, 5/2010.

[7] http://www.metsahovi.fi/pub/evn-om/4fs-4.html