EVN Upgrade to 4 Gbit/s

Introduction

This document outlines a recommended upgrade path to equip the EVN with 4 Gbit/s recording capability for routine operations. The recommendations result from discussions in the TOG 4 Gbit/s subcommittee during the period 2007 to April 2008 and are being passed on to the EVN Board of Directors through this document.

A major assumption in the text below is that the devices Mark 5C and DBBC can be made to work as advertised. Any implementation in the field or at correlators will first require detailed testing. The pros and cons of DBBC versus NRAO's sampler/filter module are not discussed in detail.

NRAO will upgrade the VLBA to 4 Gbit/s capability in early 2009 (or late 2008).

The operation will initially be restricted to very few observations mostly due to lack of disks. Sustained 4 Gbit/s recording is planned for 2011 as funding permits. NRAO is not planning to implement e-VLBI. Downstream from the IFs the VLBA acquisition system will be replaced by the following:

1. Sampler/Filter Module: two ROACH plus sampler plus clock generator. Data will be output to 10G Ethernet. Each ROACH can hold up to four Digital Down-Converters (DDC). Alternatively a polyphase filterbank (PFB) personality can be loaded. This is being developed by Haystack as a further development of their original DBE.
2. Mark 5C: will have 10G Ethernet input and will record a maximum data rate of 4 Gbit/s. Operation at this rate requires recording on 16 disks simultaneously. NRAO plans to skip Mark 5B and upgrade its Mark 5A units to Mark 5C as soon as possible.

In the VLBA's normal two-IF mode, each ROACH board will process a single IF. The infrequently-used four-IF modes will be supported, at somewhat reduced functionality, by processing two IFs on each ROACH. This might mean that only two DDCs would be available per IF, and/or the filtering in each DDC might be less "beautiful".[1]

The Mark 5C is under development by Conduant Corporation, in collaboration with Haystack and NRAO, first Mark 5C prototypes are expected summer 2008. The Mark 5C will have a Mark 5B emulation mode, which will allow data recorded with a Mark 5C unit in this mode to be played back with a Mark 5B unit and correlated with a MK IV correlator[2]. The "Mark 5C native mode" is a very simple data format and has to be generated by the digital sampler/filter unit (e.g. DBBC), which outputs the data in this format on 10 Gbit Ethernet. Data input to a Mark 5C recorder is via 10 Gbit Ethernet. (The Mark 5C recorder will actually record the payloads of any stream of Ethernet packets, subject only to minimal packet-structure requirements.)

Correlation of Mark 5C recorded data will be done at NRAO with the DiFX software correlator.

The JIVE MK IV correlator will fully support Mark 5B in the next few months

The EVN has agreed a few years ago to switch its recording systems at the telescopes to Mark 5B when JIVE can support **native** Mark 5B playback. This will allow JIVE to remove the failure-prone station units. JIVE can support Mark 5B recorded data now, but eVLBI with

1 This implies that insufficient rejection of the out of band signal could reduce the SNR under some circumstances.
2 Requires Mark IV correlator 'slowdown' above 1 Gbit/s.

Mark 5B at the stations is still under development.

Mark 5A recordings cannot be correlated with Mark 5B playback units! (see Table 1 for an overview), though a few Mark 5A playback units might remain on the JIVE correlator to support processing of Mark 5A recordings.

Correlation of global network observations in the transition phase has to be coordinated between the EVN and NRAO.

Consequences for EVN stations

Mark 5B at JIVE and Mark 5C at NRAO require that the EVN stations upgrade from Mark 5A to either Mark 5B, Mark 5B+ or Mark 5C (see compatibility table).

1. A Mark 5B/B+ can be connected to the old acquisition rack with a special interface card (VSI4 or Metsähovi board). Maximum bitrate is about 1 Gbit/s, depending on the number of BBCs.
2. A Mark 5B/B+/C can be connected to a DBBC (with FiLa10G for Mark 5C), replacing the old acquisition rack. (NRAO's sampler/filter module can only be connected to a Mark 5C, some parts of the old rack have to be retained.)

Only very few EVN stations (e.g. Yebes) ordered a VSI4 card from Haystack. Most EVN stations want to go to a DBBC directly.

Upgrade path for the EVN

For all upgrades the DBBC is the critical item! The EVN should give support to the development of the DBBC as suggested by Tuccari (see report to CBD). Components of an upgrade and their status are as follows:

1. **DBBC.** The DBBC will be able to deliver a data rate of 4 Gbit/s.
    - The software development is somewhat behind plan. Here additional manpower support from the EVN could speed up the project significantly.
    - The hardware seems to be well advanced and will be ready in time. The Ethernet connection “FiLA10G” is under development now.
    - Testing has to be intensified. The Core2 module is essential here as the Core1 is limited in capacity, and the EVN stations will order DBBCs with Core2 modules. Core2 prototypes are in hand, but support with testing and volume production will speed up the project.
    - A flow path for production is currently being established: A company is being set up which will coordinate card production, assemble and sell DBBCs.
    - The cost of a DBBC will depend on the desired capability. The system can be expanded at any time. Additional features like RFI mitigation or band equalization can be added. The cost of the components are: base system (power, PC, box, cabling, synthesizer, etc.) 9500 €, AD-converter1 2000 €, Core2 4000 €, analogue conditioning module 2000 €. The options are (price range from: only ADCs + Core2 boards to full system):
        - minimal setup with 1 AD-converter and 1 Core2 module. 6000 € (only 2 boards)
        - NRAO equivalent with 4 AD-converters and 2 Core2 modules. 16000 € to 33500 €

- EVN/geodesy compatible DBBC with 2 ADs and 4 Core2 modules. 12000 € to 25500 €
- Direct eVLBI compatibility could be provided via the FiLA10G board. ~5500 €

2. **Upgrade of Mark 5A**. Given the three alternatives below, it would be more economic to upgrade to Mark 5C directly, provided that field tests are successful. Only Mark 5C will allow the EVN to participate in global VLBI observations at 4 Gbit/s.
   - Mark 5B: $ 3500 upgrade from Mark 5A. Maximum bitrate is unchanged 1 Gbit/s.
   - Mark 5B+: additional $ 10000 for Amazon Streamstor card. Maximum bitrate 2 Gbit/s. This is a tested system.
   - Mark 5C: $ 12000 to $ 14000 for Amazon Streamstor card plus Ethernet daughter board. A direct upgrade to Mark 5C saves $3500. Planned maximum bitrate 4 Gbit/s.
3. **Correlation**
   - EVN or global observations at data rates *below* or equal to 1 Gbit/s can be correlated with the JIVE MK IV correlator and Mark 5B playback units.
   - EVN or global observations at data rates *above* 1 Gbit/s can be correlated at JIVE with the MK IV correlator, if the data is recorded with Mark 5B+ or Mark 5C in 5B compatibility mode and if slow-down can be implemented on the correlator. **The implementation of slow-down should become a priority at JIVE. As an alternative such data could be correlated with a software correlator** as NRAO or Bonn will do.
4. **Implementation**. Upgrades of the EVN and VLBA should be synchronised to avoid compatibility problems as much as possible. Details should be worked out by the TOG in collaboration with NRAO. The availability of the DBBC is a critical item for the EVN. The Mark 5Bs can only be upgraded to 5C in the field, once we have verified that a Mark 5C will work transparently in place of a Mark 5B, including observing and correlation.
5. **Observing 4 Gbit VLBI with the EVN**
   4 Gbit/s can be sampled with 2-bit sampling from 2 × 500 MHz bandwidth. The best bands for 4 Gbit/s observing in the EVN were identified by a survey conducted by M. Lindqvist[3] to select the bands in which a number of EVN stations can offer the required receiver and IF bandwidhts. The result is as follows:
   - 6 cm (Onsala – IF limited, Jodrell, Torun, Shanghai, Medicina, Effelsberg)
   - X-band (Onsala, Shanghai, Medicina, Metsähovi, Effelsberg)
   - 1.3 cm (Onsala, Jodrell, Shanghai, Medicina, Metsähovi, Effelsberg)
   - 7 mm (Onsala, Metsähovi, Effelsberg)

   A problem that needs careful attention is that the frequency ranges of the different receivers do not always overlap. **This has to be negotiated also with the VLBA.**
   Upgrading the receivers and IF systems to at least **500 MHz and where possible up to 2000 MHz** should be made official EVN policy. 16 Gbit/s VLBI systems are already being developed at Haystack. VLBI at the higher frequencies would profit most from a further increase in sensitivity.

3 not all telescope friends sent replies for the survey

Summary

The EVN can at some moderate cost upgrade the VLBI backends to 4 Gbit/s. The recorder of choice is the Mark 5C, as it can record in Mark 5B format and in addition can record 4 Gbit/s. The step from the originally planned Mark 5B upgrade to Mark 5C costs about 6000 €. The DBBC with at least four Core2 boards will provide compatibility with all present geodetic and astronomical VLBI which is based on Mark IV and VLBA record terminals. It will also be compatible with NRAO's and Haystacks sampler/filter units.

EVN's “classical” VLBI with correlation at JIVE will be possible. eVLBI will be easier with the DBBC and could be boosted to 4 Gbit/s. EVN's recorded 4 Gbit/s VLBI (like eVLBI at that rate) requires additional efforts on the correlator side.

A number of EVN stations have receivers and IF systems which will allow VLBI at 4 Gbit/s. All stations should plan for upgrades of IFs and receivers to allow higher VLBI data rates. Bandwidths of 2 GHz should be the aim.

playback with record with	Mark 5A	Mark 5A+	Mark 5B	Mark 5B+	Mark 5C[4]
Mark 5A	1 Gbit/s[5]	1 Gbit/s	-	-	See footnote 4
Mark 5B	-	1 Gbit/s	1 Gbit/s	1 Gbit/s	See footnote 4
Mark 5B+	-	1 Gbit/s	1 Gbit/s	2 Gbit/s, playb. 1 Gbit/s	See footnote 4
Mark 5C[6]	-	1 Gbit/s	1 Gbit/s	2 Gbit/s, playb. 1 Gbit/s	See footnote 4

Table 1: Compatibility between different kinds of recording and playback system.

4 Mark 5C plays back every format, but only software correlators can be programmed to make use of the resulting data stream. Playback rate is limited only by host motherboard and NIC card hardware/software.

5 Mark 5A recording and playback is limited to 512 Mbps in VLBA format.

6 Mark 5C can be played back on Mark 5B if the data was recorded in compatibility mode

Mark 5 Upgrade Costs

Target / Existing	**Mk5A**	**Mk5B** (requires VSI-H data source)	**Mk5B+**	**Mk5C** (not yet available; rough estimates)
0	Unavailable	$20.8K	~$22.3K	$20-25K
Mk5A	-	~$3.5K (Mk5B I/O)	~$13K (Amazon plus Mk5B I/O)	Est. $12-14K (Amazon plus 10GigE DB)
Mk5B	-	-	~$9.6K (Amazon)	Est. $12-14K (Amazon plus 10GigE DB)
Mk5B+	-	-	-	Est. $2-4K (10GigE DB)

Note: Costs do not include cost of creating data source

Table 2: from Whitney's presentation at the last TOG meeting