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Geodetic S2 VLBI: International Plans

Calvin Klatt [1], *Mario Bérubé* [1], *Wayne Cannon* [2], *W.T. Petrachenko* [1], *Anthony Searle* [1]

[1] *Geodetic Survey Division, Natural Resources Canada*

[2] *York University, Department of Physics and Astronomy and Space Geodynamics Laboratory/CRESTech*

Contact author: Calvin Klatt, e-mail: `cklatt@nrcan.gc.ca`

Abstract

International use of the S2 geodetic system is beginning in 2002 after a successful series of experiments in Canada that began in 1999. The S2 Recording Terminal (RT), which utilizes commercial VCR tape transports, has been used internationally for several years. The S2 Data Acquisition System (DAS) is designed for geodetic usage and differs from the Mk3/Mk4 mainly through its use of rapid frequency-switching to achieve the necessary delay resolution. Correlation is performed at the 6-station Canadian Correlator, which has been used extensively for many years by the Space-VLBI community.

We review the geodetic experiments that have been performed in Canada using the Algonquin, Yellowknife and CTVA antennas. In 2002 a network of stations equipped with S2 systems will be included in the IVS observation program. The goals of this international series of experiments will be discussed as well as our future plans.

1. S2 Overview

1.1. Hardware Status

The Canadian S2 VLBI system includes the recording terminal, the frequency switched VLBI data acquisition system, and the S2 correlator.

The record terminal is a 128 Mbit/sec, Mostly-Off-The-Shelf (MOTS) system based on an array of eight video tape transports. The extensive use of MOTS hardware in the S2 design resulted in a low cost, high performance, VLBI data record/playback system of which more than 50 have been fabricated and are now in use in a variety of radio astronomy and VLBI applications in more than a dozen countries around the world.

The S2 DAS, when configured for geodetic applications, includes two baseband converters, each with a frequency agile local oscillator (LO). The baseband channelization modes of the S2 DAS BBCs are completely compatible with those of the VLBA/Mk-IV. The frequency agile LO was incorporated to enable high sensitivity group delay measurements without appealing to a more costly parallel IF/baseband sub-system.

The Canadian correlator is an (expandable) six station correlator using S2 playback terminals and is designed to handle S2 frequency switched bandwidth synthesis data.

All of these components are necessary for geodetic S2 VLBI to take place. Many stations have an S2 RT which is not paired with an S2 DAS and hence these stations are not equipped to operate in an S2 geodetic network. Furthermore, it should be noted that the S2 DAS frequency switched geodetic mode and the usual Mk-III/Mk-IV DAS geodetic mode are not compatible with each other.

Given the availability of a large number of recording terminals and a correlator, the main limitation to the expansion of geodetic S2 operations is the availability of the S2 DAS.

At this time seven DASs have been manufactured. Three are located at the Canadian stations (ARO, YELO, CTVA) and one is owned by BKG and will be used at TIGO. One will remain in Toronto for development/user-support and two can be deployed elsewhere. Three of these DASs are currently in final operational testing, two for GSD and one for BKG. We intend to update all of the DASs during 2002 with hardware modifications and improvements that have occurred as a result of recent usage.

1.2. Experiment Scheduling and Operations

The standard geodetic VLBI scheduling tools, SKED/DRUDG, now support the S2 RT but not the DAS.

The use of the S2 RT is quite simple and it is fully supported by the PCFS. 128 Mbits/sec are recorded onto 8 parallel VCR transports. Cassette motion is continuous (making recovery from failures very simple) and tape changes occur every six hours. For the S2 RT and DAS status monitoring and control is available via a console (or ethernet).

The DAS is similarly easy to operate. While formal PCFS support is still being discussed we have implemented the capability for mode setup and loading of frequency sequence from the PCFS at the Canadian stations. The DAS has a power on self test and system testing via phase cal extraction/monitoring is available.

We currently operate the DASs with two BBCs. The frequency sequence we have typically used involves 12 steps with a 1 sec dwell time, giving 24 "virtual frequencies".

1.3. Correlation

The Canadian correlator is located at the Dominion Radio Astrophysical Observatory near Penticton, B.C. A large tape library is available for Space-VLBI which we have access to. The correlator has six playback terminals (PTs) and is easily expandable to ten. The correlator was designed for geodesy and space-VLBI projects (Japanese VSOP/MUSES-B) and has been in production mode (astronomy) for approximately five years.

Support for geodetic data switching schemes are complete and efforts continue to enhance the tools used for examining data quality.

1.4. Analysis

The official S2 correlator export output is in the UVFITS format, which is then "fringe'd" and output in the "CGLBI" format. A software program called "CGLBIDB" converts this to a Mk-III database for further analysis in CALC/SOLVE. Analysis in CALC/SOLVE is virtually identical to that for Mk-III/IV data.

Because of the wide single band channel (16 MHz), the wide ambiguity spacing (200ns) and the use of all 16 of the PCAL tones in each band, we do not see any group delay ambiguities. In our standard small network analysis, ALGO is held fixed and apriori EOPs and Nutation are used. Typical group delay residuals after analysis are 25-50ps, consistent with the SNR obtained and the delay resolution function.

Software for data quality analysis is available and further developments are underway.

1.5. Further Developments

The areas of most active development include:

- S2 DAS cleanup (updating early production systems, documentation, etc.)
- S2 DAS support in PCFS
- Frequency-switching sequence optimization (S-band interference / 1 BBC operations)
- Interpretation of geodetic results

2. Experiments Performed

The experiments conducted to date utilized the Algonquin Radio Observatory, the Yellowknife Geophysical Observatory, and the Canadian Transportable VLBI Antenna - CTVA (see Table 1).

Table 1. Canadian VLBI Stations

Station Name	Antenna Diameter (m)	X SEFD	S SEFD	Equipment
Algonquin	46	200	250	VLBA4, Mk-III, S2
Yellowknife	9	7600	6500	Mk-III, S2
CTVA	3.6	$\sim$ 70,000	$\sim$ 70,000	S2

Note that at 128 Mbits/sec, the ALGO-CTVA baseline is approximately as sensitive as two 16m antennas at 56 Mbits/sec. The YELO-CTVA baseline is very weak, producing very few scans. 44 experiments have been performed but many were system tests and some geodetic experiments failed to produce results of sufficient quality for geodetic interpretation.

2.1. Results: "PENTICTN"

From June 1999 to June 2001 the CTVA was located near Penticton, B.C., near the location used by the NASA transportable in the 1980s. See Figure 1 for baseline results of S2 experiments involving the CTVA at Penticton.

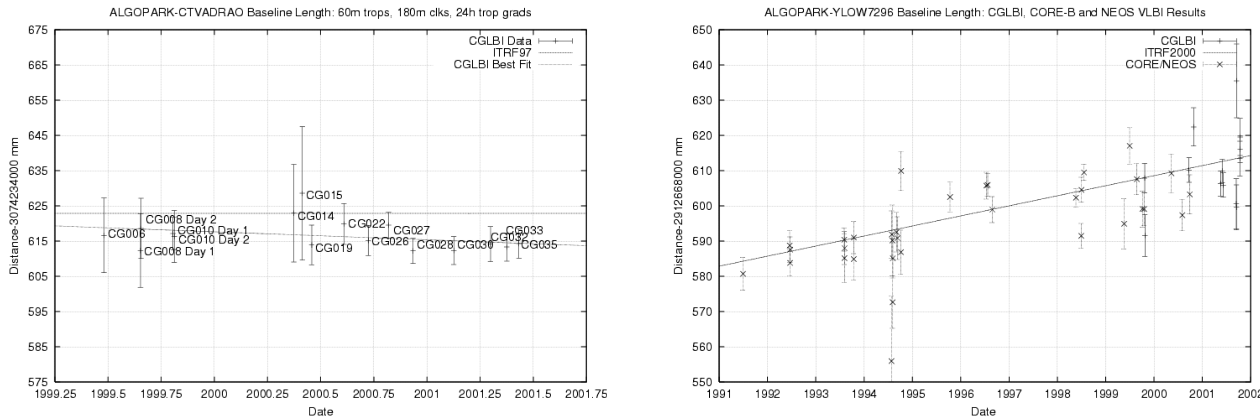
Table 2 compares the results from the Goddard Solution 2001c (third week of May, 2001), which includes Mk-III data only, and the GSD Global solution performed on May 7, 2001 which includes Mk-III data supplemented by the S2 data. The large difference in the results is due to the additional data used in the GSD analysis.

2.2. Mk-III and S2 Results: "YELO7296"

Figures 1 gives baseline length results of ten years of Mk-III and S2 experiments involving YELO7296. The S2 experiments begin in late 1999. There appears to be little to distinguish the Mk-III from the S2 data. A line giving the ITRF2000 position (determined by GPS and VLBI) is also shown.

2.3. Summary

Given the results obtained using the S2 system, we can conclude that the S2 system performance meets expectations. The system's capability is, therefore, largely determined by the data rate,



Penticton Baseline Results

Yelowknife Baseline Results

Figure 1. **Results**

Table 2. Global Solution Results: PENTICTN

Solution	**X** mm Sigma	**Y** mm Sigma	**Z** mm Sigma	**Vx** mm/yr Sigma	**Vy** mm/yr Sigma	**Vz** mm/yr Sigma
GSFC	-2058840546.1	-3621286535.2	4814420846.0	-22.8	-12.4	8.7
	28.0	44.8	58.5	3.4	5.6	7.1
GSD	-2058840505.6	-3621286723.1	4814420723.1	-19.2	-3.1	-3.0
	2.50	4.4	5.4	0.6	1.0	1.3

128 Mbits/sec. The Mk-III system operates at 56 Mbits/sec and the Mk-IV has recently begun operations at 256 Mbits/sec. Each factor of 2 increase in data rate allows scan lengths to be halved *or* gives an SNR increase of root 2. There is some debate how much increases in data rate (either number of scans or SNR) help us do geodesy. Refer to the paper by Dan Macmillan (NVI/GSFC), this volume, on simulations performed using higher data rates.

3. The Future of S2-based Geodesy

> "Deployment of geodetic S2 and K4 systems at more stations is encouraged so that good geodetic networks can be designed that use these systems and be integrated into the international geodetic observing program."

Recommendation of IVS WG2

3.1. The E3 Network in 2002

The S2-based IVS E3 network will begin operations in March 2002. For 2002 the network will operate monthly, with weekly operations in future years being discussed. In addition to the three S2 equipped stations in Canada (See Table 1), the Canadian contributions to this effort include:

- Tape Supply
- Correlation
- Scheduling/Analysis Support
- Loans of S2 DASs to up to two partners and possible RT loans

Current partners in this effort include BKG which has purchased both an S2 RT and a DAS for use at TIGO which will be operated in Chile. NASA will be operating Kokee in this network this year with an RT borrowed from an Australian group and a DAS on loan from NRCan. There has been some discussion of adding NOTO to the network in the autumn. Additional stations could participate in this network using equipment on loan from NRCan.

Since the E3 network will initially be very small (three stations), and will include two stations whose position is poorly determined, we cannot reasonably expect high precision EOP results in 2002. In the medium term the goals of the E3 network are to provide EOP results with accuracies comparable to similar Mk-IV networks. This effort will be delayed by the need to obtain position information for the TIGO and CTVA stations. The fundamental limitations of the E3 network are the same as those for any Mk-IV network: network design, data rate, etc.

3.2. Future Opportunities

We hope to add additional stations to the E3 network starting in the summer of 2002. A number of stations are already equipped with S2 RTs and would require DASs on loan from NRCan. The number of available S2 RTs is expected to increase as the VSOP space-VLBI mission winds down. These RTs are expected to become the property of NRCan or CRESTech and could be loaned out.

In loaning S2 equipment NRCan hopes to strike an optimum balance between working with stations that strengthen the network (e.g. Kokee), working with partners that have or will purchase equipment (e.g. TIGO) and assisting interested partners that have difficulty purchasing equipment. We feel that additional purchases of S2 DAS equipment are necessary for the continuation of the IVS E3 network.

Stations that have S2 RTs (through purchase or loan) need only purchase the DAS component (about 130K USD) to contribute. Ideally, we would like stations to obtain a complete set of S2 RT, DAS and Playback Terminal (PT) (at a cost of 200K USD if free RTs are available). The PT would be used at the correlator to increase its capacity. Each S2 RT/DAS/PT added to the S2 World increases the network size.

With four such additions we could operate a ten-station S2 network, significantly enhancing the VLBI product through greater network strength.