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The S2 VLBI System: DAS, RT/PT and Correlator

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Abstract

The S2 VLBI system synthesizes wide IF bandwidths by rapidly switching the local oscillator (LO) frequency in a small (1-4) number of baseband converters (BBC's). Data are recorded on video cassettes using an array of 8 VHS transports. Characteristics of the S2 Data Acquisition System (DAS), the S2 Record and Playback Terminals (RT and PT) and the S2 Correlator are summarized. The bandwidth synthesis (BWS) frequency switching sequence used in a series of system validation experiments is presented.

1. Introduction

A major component of the Canadian Geodetic VLBI (CGLBI) Program involves the development of VLBI instrumentation for geodetic applications. The S2 VLBI system, including DAS, RT/PT and Correlator is a product of this effort.

The S2 is a general purpose VLBI system capable of a wide range of applications including geodesy/astrometry, astronomy (continuum, line and pulsar), and space VLBI. The successful application of the S2 DAS to geodetic applications is based on its use of LO's which can switch frequencies quickly. Each BBC LO is programmed to cycle through a set of frequencies sequentially, making it possible to synthesize wide IF bandwidths with a small number of BBC's. Since the sequences are flexible, this approach is very adaptable.

The S2 VLBI system is now essentially complete. Over the past several months, it has been undergoing a number of system validation tests. The tests have included five 24-hour geodetic observing runs (see Ref. [1]) and a few shorter tests which involve the continuous tracking of a single source.

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2. S2 System Description

2.1. S2 Data Acquisition System (DAS)

At the heart of the S2 system's geodetic capability is the design of the BBC LO system (see Figure 1). In the S2 DAS, baseband conversion is a two-step process. Step 1 is an up-conversion using a 1350–2250 MHz frequency agile LO with settling time <1 ms and resolution 1 Hz. The effect of this mixing stage is to translate any frequency within the 100–1000 MHz IF input range up the centre of the 1225–1275 MHz bandpass filter. In step 2, the bandpass filter output is translated to baseband using a single sideband mixer (SSBM) and a fixed LO at 1250 MHz.

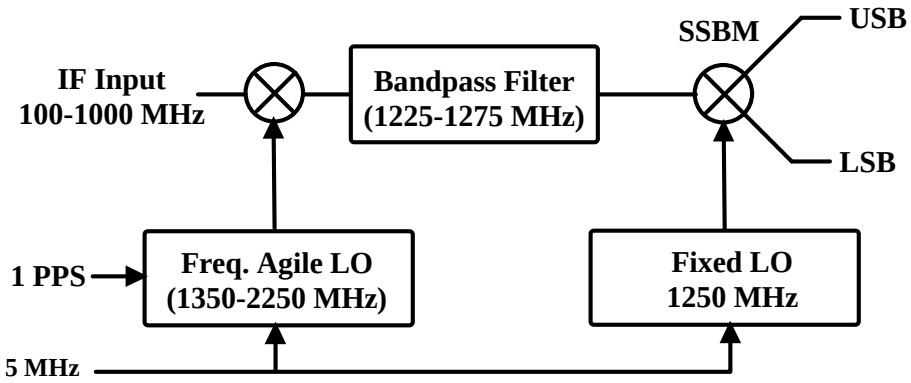

Figure 1. S2 BBC LO System.

The S2 BBC LO design provides two important advantages: 1) The two-step baseband conversion makes it possible to process the entire 100–1000 MHz IF input range independently in each BBC, i.e. no external IF processing steps, such as splitting of the IF input into sub-bands or the use of external mixing stages, are required to handle the 720 MHz X-band IF. 2) The rapid switching capability of the LO makes it possible to synthesize wide effective bandwidths by cycling through a sequence of LO frequencies, effectively removing the need for a large number of BBC's.

Characteristics of the S2 DAS are summarized below:

- Up to 4 IF inputs (100–1000 MHz) and 4 BBC's.
- Flexible switching of IF inputs to BBC's.
- Maximum output data rate, 512 Mbits/s.
- Phase coherent fast frequency switching LO: maximum switching rate, 50 Hz; settling time <1 ms; phase noise <2 degrees rms; frequency resolution, 1 Hz.
- VLBA compatible baseband channelization and sampling: bandwidths from .0625 to 16 MHz in factors of 2; 1 or 2-bit sampling with rate 32 Msamples/s.
- Data Quality Analysis: 2 PCAL tone extractors per BBC; one stream statistics accumulator per baseband channel.
- Control via terminal, serial multi-drop protocols, or Ethernet.
- Extensive debugging and self-test capabilities.

2.2. S2 Record and Playback Terminals (RT and PT)

The S2 RT and PT were the first components of the S2 VLBI system to be completed. They have been fully operational since the early 1990's and can be found at more than 20 radio telescopes world-wide, at three NASA Deep Space Network complexes where they are used for space VLBI and at two fully operational VLBI correlators. Architecturally, the RT and PT are made up of an array of 8 SVHS transports and a VME controller. The technology is mature, robust and the systems are convenient to use. SVHS cassettes are inexpensive and easy to handle.

Characteristics of the S2 RT/PT are summarized below:

- Data rates up to 128 Mbits/s.
- 6 hours continuous recording at 128 Mbits/s.
- BER in LP ≈1.e-5; BER in SLP ≈3.e-4
- Low media cost ($37 US per Tbit).
- S2 RT can be interfaced directly to the Canadian S2 DAS, the Australian S2 DAS and "other" DAS's in Russia and China.
- S2 RT can be interfaced to VLBA, Mk4, K4/VSOP or Australian LBA using S2-VIA module.
- S2 PT has a clean format-free non-data-replacement output interface.
- Control via terminal, serial multi-drop protocols or Ethernet interface.
- Supported by NASA VLBI Field System (PCFS).
- Extensive diagnostics, self-test and calibration software.
- Uses proven, reliable SVHS industrial transports.
- Transportable configuration includes 3 modules each weighing less than 37 kg.

2.3. Canadian S2 VLBI Correlator

The Canadian S2 VLBI Correlator (see Ref. [2]) was initially designed as Canada's contribution to the RadioAstron space VLBI project. It has many unique features for processing pulsar, spectral line and space VLBI data. With respect to geodetic applications, it handles the frequency switched BWS modes of operation. The correlator has been in full operational status for over 3 years in support of the VSOP and CGLBI programs.

Characteristics of the Canadian S2 VLBI Correlator are summarized below:

- XF station-based architecture.
- 6-station correlator.
- Handles 8 baseband channels per station/baseline.
- Channels can be 1 or 2-bit sampled at up to 32 Msamples/s.
- 8 sets of stream statistics and 8 9-bit tone extractors per station module.
- Two independent pulsar gates per station module.
- Handles the high fringe rates & accelerations characteristic of satellites (including perigee).

- Extensive diagnostic and self-test capability.
- Frequency switching capability.
- Up to 16,384 lags per baseline in spectral line or fringe search mode.
- Correlator "dump" interval as short as 1 ms.
- Standard output product for astronomy is "UVFITS".
- Utilities available to translate the geodetic multi-band "FRINGed" output into Calc & Solve dbase format.
- Special lag architecture and internal digital filters allow mixed bandwidth correlation as well as "zoom" mode for enhanced spectral line capability.

3. Frequency Sequence Design

3.1. S2 Frequency Sequence Capabilities

The S2 system was designed to provide a great deal of flexibility with respect to the implementation of frequency switched BWS. There are several factors that contribute to this flexibility.

1. IF Input Range. The IF input range is 100–1000 MHz. This allows IF channels up to 900 MHz bandwidth to be handled without band splitting.

2. Number of IF Inputs. Hardware for up to 4 IF inputs can be installed. This is more than adequate to handle the S-band and X-band inputs used in geodetic VLBI. The extra IF inputs could be used for additional bands, polarizations or to handle IF's wider than 900 MHz.

3. Number of BBC's. Up to 4 BBC's can be installed. This provides up to 4 simultaneous BWS frequencies and a potential output data rate of 512 Mbits/s.

4. Maximum Frequency Switching Rate. The maximum frequency switching rate is 50 Hz with LO switching transients settling in <1 ms.

5. Maximum Sequence Length. A sequence can have up to 16 unique states and (since states can occur more than once in a sequence) a total of 64 elements. For a 2 BBC system, the net effect is equivalent to 32 "virtual" BBC's. The sequence length limits are imposed in software and could be relaxed if necessary.

6. Sequence Length. The DAS software calculates which element of the frequency switching sequence to use at any particular time by assuming that the sequence starts at the beginning of the UT day. Removing the need to have a command to set the epoch at which the sequence starts makes the frequency switching command structure simpler and operationally more robust. A consequence of this assumption is, however, that the sequence length is constrained such that an integer number of cycles of the sequence must occur in a day.

7. LO Frequency Setting Resolution. The BBC LO frequency setting resolution is 1 Hz. This makes it possible to offset the LO frequency away from integer multiples of 1 MHz to avoid corruption of the PCAL tones.

3.2. Frequency Sequence for the S2 System Validation Tests

A BWS frequency switching sequence was selected to be used in the S2 system validation experiments. The design goal for the sequence was to match the performance of typical Mk3

sequences with respect to spanned bandwidth, rms bandwidth, ambiguity spacing and maximum sidelobe level. The sequence selected (see Table 1) uses a frequency switching period of 1 second per state and a total of 12 states.

State	X	S	BBC1(MHz)	BBC2(MHz)
1	•		8212.99	8932.99
2		•	2227.99	2352.99
3	•		8502.99	8642.99
4		•	2272.99	2307.99
5	•		8217.99	8972.99
6	•		8422.99	8722.99
7		•	2232.99	2347.99
8	•		8237.99	8907.99
9		•	2247.99	2332.99
10	•		8307.99	8837.99
11		•	2237.99	2342.99
12	•		8277.99	8867.99

Table 1. Frequency sequence used in the S2 system validation tests.

The performance of the sequence in Table 1 is summarized in Table 2. It very nearly matches the performance of the most commonly used Mk3 sequence except that it has the advantage that the X-band ambiguity spacing is 200 ns instead of 50 ns. The sequence performed very well in the system validation experiments. There was essentially no evidence of misidentification of fringes other than when signal levels were near or below the detection threshold.

Parameter	X-band	S-band
Spanned BW (MHz)	720	125
RMS BW (MHz)	280	49
Max sidelobe (%)	56	62
Ambiguity (ns)	200	200

Table 2. Performance of the frequency sequence used in the S2 system validation tests.

References

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