The VLBI Digital Terminal at NASA's Deep Space Network: Enhancements for External VLBI Users

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The Deep Space Network (DSN) has replaced the Mark IV Data Acquisition Terminal (DAT) with a digital backend, the DSN VLBI Processor (DVP). The DVP is an in-house Jet Propulsion Laboratory (JPL) development that uses hardware from the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER) for real-time digital signal processing and channelization and streams the data into a Mark 5C recorder in VLBI Data Interchange Format (VDIF). This contribution presents recent enhancements made to the DVP application to improve our support to the international VLBI networks.

Keywords: VLBI, Digital Backend, Digital Signal Processing.

1 Introduction

The large and sensitive antennas of the NASA's Deep Space Network participate in the observations of the European VLBI Network (EVN), the International VLBI Service for Geodesy and Astrometry (IVS), and the Australian Long Baseline Array (LBA), among others. These observations are supported using a modern digital backend system developed in JPL, the DSN VLBI Processor (DVP). Efforts to validate its proper function and interoperability have already obtained positive results, e. g. with the European VLBI Network (García-Miró *et al.*, 2014 [2]). This contribution focuses on the recent enhancements performed to the DVP application to improve its compatibility with similar digital backends.

2 DSN VLBI Processor Overview

The DSN VLBI Processor -DVP- (Navarro *et al.*, 2011 [5]; García-Miró *et al.*, 2012 [3]), is a recent JPL development to support VLBI observations in the DSN. Following is a description of its main characteristics emphasizing certain limitations of the first operational version:

— IF switch with up to 12 inputs to record signals from different DSN antennas;

— process two IF inputs, each covering up to 540 MHz of bandwidth (100–640 MHz);

— uses JPL IF sampler module and CASPER ROACH board for Digital Processing and Channelization;

— the Mark 5C recorder is used for data recording with SDK 9.2. Data is stored on Mark 5 modules in DSN VDIF format: single data threads carrying multi-channels data frames. Limited to use $\leq$ 16 TB Mark 5 disk modules;

— interfaces to Deep Space Network monitor & control infrastructure;

— independently of the configuration mode, it ALWAYS records 32 real upper/lower or 16 complex channels (in-phase and quadrature-phase). Supported bits per channel = 8, 4 or 2 bits. Maximum date rate is 2048 Mbps therefore channel maximum bandwidth is 16 MHz (or 32 MHz for complex channels). As a result recording data rate is higher than required for certain configurations with subsequent waste of recording media;

— VDIF legacy headers (16-bytes) instead of full headers (32-bytes);

— dual bank recording not available, maximum recording data rate is 2048 Mbps. Bank switching during recording not operational;

— phase calibration signal real time detection;

— VEX files used for input from the users;

— partially compatible with other digital developments (DBBC, RDBE, etc.), not able to support standard 2 Gbps EVN observations with 32 MHz bandwidth real USB/LSB channels.

3 DSN VLBI Processor Enhancements

Motivated by the need to standardize the DSN VDIF format and improve compatibility with other digital VLBI terminals, a new version of the DVP application, RSO-6726-OP-B V2.4.3, has been implemented during year 2016, and is currently under testing. This new DVP version contains following improvements for our support to external VLBI users:

— DSN VDIF format: introduce 32-bytes headers for all external users. Legacy headers still available;

— DSN VDIF format: possibility to record ONLY 2, 4, 8 or 16 complex channels (or 4, 8, 16 or 32 real USB/LSB channels), decreasing recording data rate for certain configurations (Table 1). Maximum data rate is 2048 Mbps;

— DSN VDIF format: possibility to use 64 MHz complex channels (or 32 MHz real USB/LSB channels) for 2 Gbps recordings;

— DSN VDIF format: 1, 2, 4, and 8-bit per sample available;

— Mark 5C upgraded to SDK 9.4: allows to use $>$ 16 TB SATA Mark 5 disk modules;

— Mark 5C PC upgraded from Debian Linux 6.0.7 32-bit to Debian Linux 7.10 64-bit;

— DVP control computer upgraded from Debian Linux 6.0.7 64-bit to Debian Linux 8.4 64-bit;

— Includes antenna status and weather data in experiment logs;

— More reliable calculation of total power in 2-bit sampled channels;

— Dual bank recording not yet implemented. Bank switching during recording problems fixed;

— Several bug fixes for overall robustness.

Table 1

DVP new recording modes, including standard EVN mode for 2 Gbps supports with 32 MHz bandwidth real channels. NOTE: only 1 and 2 bit modes specified, modes with 4 and 8 bit also available

Number of Channels		Sample	Complex channel	USB/LSB channel	Data Rate Mb/s
Complex	USB/LSB	Bits	size (MHz)	size (MHz)	
16	32	1	64/40/32/16/8/4/2	32/20/16/8/4/2/1	2048/1280/1024/512/256/128/64
16	32	2	32/16/8/4/2	16/8/4/2/1	2048/1024/512/256/128
8	16	1	64/40/32/16/8/4/2	32/20/16/8/4/2/1	1024/640/512/256/128/64/32
8	16	2	64/40/32/16/8/4/2	32/20/16/8/4/2/1	2048/1280/1024/512/256/128/64
4	8	1	64/40/32/16/8/4/2	32/20/16/8/4/2/1	512/320/256/128/64/32/16
4	8	2	64/40/32/16/8/4/2	32/20/16/8/4/2/1	1024/640/512/256/128/64/32
2	4	1	64/40/32/16/8/4/2	32/20/16/8/4/2/1	256/160/128/64/32/16
2	4	2	64/40/32/16/8/4/2	32/20/16/8/4/2/1	512/320/256/128/64/32

4 Amplitude Calibration with the DVP

Continuous calibration has been implemented to provide calibration data for the VLBI observations supported with the DVP. During the observations a noise diode with noise of about 3–6 % of the system temperature is modulated at 10 Hz, that is the standard DSN modulation. After the observation corresponding calibration rxg files are provided to the correlator. Moreover the EVN software correlator at JIVE (SFXC) can now support continuous calibration at this 10 Hz modulation frequency, in addition to the 80 Hz frequency that is more standard in astronomical VLBI. We illustrate the results obtained for an L-band observation supported in the EVN Observing Session I 2016, comparing linear system temperature measured using a Power Meter and a filtered input (method I, Fig. 1, left), continuous system temperature measured with a DSN receiver (method II, Fig. 1, left), and the system temperature extracted from the DVP data by SFXC (method III, Fig. 1, right). For

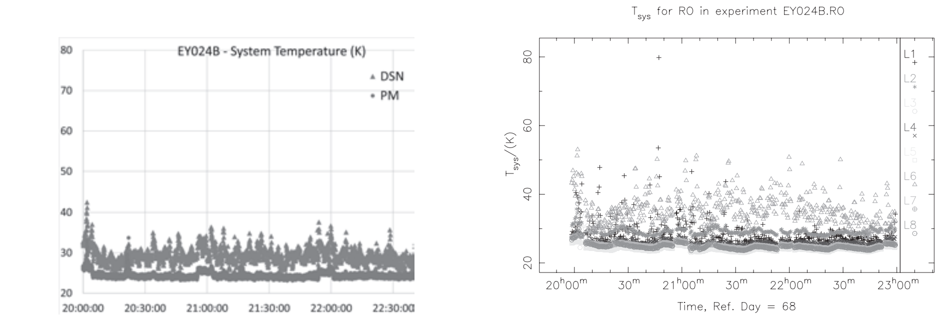

Fig. 1. *Left:* Linear System Temperature measured using a Power Meter (Method I, PM, circles) and continuous calibration using a DSN receiver (Method II, DSN, triangles). Measurements with the DSN receiver are performed in a frequency band affected by RFI. *Right:* Continuous calibration for each of the recorded channels calculated with the EVN software correlator (Method III). Results agree with PM linear calibrations (Method I) to 10 % or better. The channel affected by RFI (L6, triangles) has similar behaviour as the DSN receiver output

this particular experiment continuous calibration results from SFXC are consistent with the self-calibration from the EVN pipeline showing the viability of using method III.

5 Conclusions

The DSN VLBI digital backend has enhanced considerably the quality of the DSN VLBI observations. A new version of the DVP application has been developed to improve its interoperability in international VLBI networks and is currently under testing.

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