Postprint: Development of the DBBC2 Digital Terminal System at Nanshan Station of Xinjiang Astronomical Observatory

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Abstract

With the rapid development of computer digital technology, the Base Band Converter (BBC), a key observation terminal device required for Very Long Baseline Interferometry (VLBI), has evolved from analog systems (Analog BBC, ABBC) to digital systems (Digital BBC, DBBC). Compared with analog systems, digital systems offer high flexibility and can exponentially increase VLBI observation bandwidth, thereby meeting various high-sensitivity VLBI observation requirements. Considering these technical advantages and the important role of the Nanshan station of Xinjiang Astronomical Observatory in domestic and international VLBI networks, the Nanshan station upgraded its VLBI terminal system in 2016 by introducing a DBBC2 terminal developed by the Italian company Hat-Lab. This paper introduces the main components and working principles of the European DBBC2 system, as well as the methods for system assembly, connection, configuration, calibration, and debugging. After comprehensive inspection and testing of the system hardware and software, joint observations were conducted with major domestic and international stations, and correlated interference fringes were successfully obtained on multiple occasions. These successful observations demonstrate that the Nanshan DBBC2 system has been successfully installed and possesses high reliability. With the new DBBC2 system, the Nanshan station can participate in broadband VLBI observations with recording rates of 2/4 Gbps, which is extremely beneficial for astronomers to conduct imaging observations of fainter radio sources in the universe with milliarcsecond resolution.

Full Text

Installing a VLBI Digital Backend with DBBC2 at Nanshan Station, Xinjiang Astronomical Observatory

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Abstract

With the rapid development of computer and digital technology, the Base Band Converter (BBC)—a critical component of Very Long Baseline Interferometry (VLBI) backend systems—has evolved from analog systems (Analog BBC, ABBC) to digital systems (Digital BBC, DBBC). Compared with analog systems, digital systems offer much greater flexibility and can increase VLBI observation bandwidth severalfold, thereby meeting various high-sensitivity VLBI observation requirements. Considering these technical advantages and the important role of Nanshan Station in domestic and international VLBI networks, the station upgraded its VLBI terminal system in 2016 by introducing a DBBC2 terminal developed by Hat-Lab (Italy). This paper introduces the main components and working principles of the European DBBC2 system, as well as the methods for assembly, connection, configuration, calibration, and debugging. After comprehensive inspection and testing of the system hardware and software, joint observations were conducted with major domestic and international stations, with correlated interference fringes successfully obtained on multiple occasions. These successful observations demonstrate that the Nanshan DBBC2 system has been successfully installed and exhibits high reliability. With the new DBBC2 system, Nanshan Station can participate in wideband VLBI observations with recording rates of 2/4 Gbps, which will greatly facilitate astronomers' mapping observations of fainter radio sources in the universe with milliarcsecond resolution.

Keywords: DBBC2 System; Very Long Baseline Interferometry; Base Band Converter

1 DBBC2 System Basic Principles and Composition

The DBBC2 system consists primarily of an analog signal conditioning module, AD sampler, data processing module CORE, connection server, FILA10G module, timing and clock board, and PC components [5-6]. The intermediate frequency (IF) signal is sent to the analog signal conditioning module, where it undergoes filtering, shaping, and gain control before being sent to the AD sampler. After conversion to a digital signal, it passes through the high-speed input bus (HSI) to the data processing module CORE for digital down-conversion and filtering into a digital baseband signal. Finally, it is output via the HSO bus (High Speed Output) and the VSI interface of the second FILA board. The VSI interface can be connected to a Mark5B [1] data recording device or to the FILA10G module. A 1024 MHz frequency synthesizer generates the sampling clock required by the AD sampler. The PC component receives commands from the FS computer and controls the DBBC2 via the PCI bus. The principle is shown in Figure 1 [Figure 1: see original paper].

2 DBBC2 Structure

The DBBC2 system is housed in a chassis measuring 483 mm wide, 370 mm high, and 500 mm deep. On the lower part of the DBBC2 front panel, a blue indicator light shows that the main power switch is active, as shown in Figure 2 [Figure 2: see original paper]. On the rear panel, there are multiple connectors and interfaces, including three switches in the lower left corner—one large and two small. The large switch serves as the main connection, while among the two smaller power switches, the red button switch powers the electronic equipment and the green button switch powers the internal PC system. The power-on sequence is from left to right, and the power-off sequence is the reverse, as shown in Figure 3 [Figure 3: see original paper].

The internal structure of DBBC2 mainly comprises four major parts: the electronic section, PC section, cooling system, and power supply system, as shown in Figure 4 [Figure 4: see original paper].

3 DBBC2 Main Performance Indicators

The main performance indicators of DBBC2 [5] are shown in Table 1 .

Table 1 Performance index of DBBC2

Parameter	Specification
Built-in IF filter selectable output IF signals (MHz)	1 (1-512), 2 (512-1024), 3 (1024-1536), 4 (1536-2058)
Channel bandwidth (MHz)	V105E: 32, 16, 8, 4, 2, 1
A/D Sampler	Sampling clock: 1024 MHz
Data processing module	CORE2

Parameter	Specification
FILA 10G module	5B formatter; 10G optical fiber output; VSI input/output
1024 MHz Synthesizer	Generates system clock
Connection server	FILA board
PC Main Configuration	Windows XP system; PCI 7200; PCI9111HR; JTAG interface

4 DBBC2 Software and Observation Modes

The DBBC2 software [6] runs in the Windows XP environment. The DBBC2 control software is located in the `c:\DBBC\bin` directory, the user manual is in `c:\DBBC\doc`, configuration text files are in `c:\DBBC_{CONF}\`, and firmware is in `c:\DBBC_{CONF}\FilesDBBC`. The main software includes `DBBC2 Control DDC V105_1.exe` and `DBBC2 Control DDC V105E_1.exe`. Observation modes mainly include DDC and PFB modes. The DDC mode is tunable with channel bandwidth ranging from 1-16 MHz, upper/lower sidebands, and continuous 80 Hz synchronous calibration. Observation modes include geo, astro, astro2, W-astro, VLBA, and test. The DDC mode also includes DDC-E, which can achieve bandwidth up to 32 MHz and can be used for astro3 observation mode. The PFB mode is fixed-tuned with channel bandwidths of 32/64 MHz, all upper or lower sidebands depending on Nyquist distribution.

5.1 Hardware Connection and Self-Test

(1) Connect a 10 MHz signal with amplitude around 0 dBm and a 1 pps signal to the DBBC2 rear panel. Connect the VSI cable output from DBBC2 to Mark5B, turn on the 220V power supply, connect DBBC2 to the internal network of the VLBI terminal system, and configure the IP address. The power-on sequence is: first turn on the main power supply at the lower left of the DBBC2 rear panel, then sequentially turn on the industrial computer power and PC power.

(2) Run the DDC software on the DBBC2 Windows desktop. The system then configures the hardware, and the 4 FPGAs inside DBBC2 will be programmed and loaded with local oscillator frequencies. After programming, all LEDs on the boards display the same pattern. Observe the 4 columns of lights on the DBBC2 front panel flashing sequentially, finally synchronizing at a frequency of once per second, indicating normal DBBC2 system power-up and normal software operation.

(3) Edit the configuration file according to the manual to select different IF inputs for ADB and adjust signal amplitude through AGC. Run the `DBBC client v4.exe` program on the Windows XP desktop, and a client window will pop up. At the "Enter Command:" prompt, input relevant

commands according to the DBBC2 manual to detect DBBC IF power amplitude, bandwidth, IF attenuation, and other status parameters.

(4) Mark5B needs to synchronize the 1PPS signal transmitted via VSI cable from DBBC2. Run the `tstDIM` program [7] on Mark5B and execute time synchronization commands at the prompt according to the Mark5B manual.

5.2 Clock Calibration

Generate a 764 MHz signal with amplitude around -15 dBm using a signal generator. This signal passes through a one-to-four power splitter and outputs to IFA1, IFB1, IFC1, and IFD1 on the DBBC2 rear panel. At this time, the IF filter output selected inside DBBC2 is filter No. 2 (512-1024 MHz). For specific clock calibration steps, refer to reference [8].

6.3 FS Correlation Settings

(1) Modify the "dbbad.ctl" file in the `/usr2/control/` directory on the FS computer, writing the DBBC2 IP address into the file with port number 4000.

(2) Clock difference collection: During observations, the formatter clock needs to be compared with the GPS clock. Modify the `ibad.ctl` file in the `/usr2/control` directory on the FS computer, defining the port address number for C2 as 3 in the format `C2=dev03,0`. Run `clock` in the FS operator window to verify normal reading of clock differences.

(3) Pointing noise control: This is mainly used to control the receiver noise source [9] on/off to test system temperature. Pointing noise control is required during antenna measurements [10]. Set the serial port for controlling the pointing noise in the `stqkr.c` file in the `/usr2/st/stqkr/` directory on the FS computer in the format: `pcaltty_{numb}="/dev/ttyr03";`. After recompiling, run `cal=on` and `cal=off` commands in the FS operator window to verify normal communication.

(4) Modify the `equip.ctl` file: Select rack type as dbbc, version as v105_1, Mark5B clock rate as 32, and FiLa10G input as vsi1.

On January 12, 2017, Nanshan Station conducted S/X-band fringe test experiments jointly with Kunming Station and Shanghai Tianma Station, successfully obtaining interference fringes. On February 23 and 25, Nanshan Station performed L-band fringe test experiments with European EVN stations, also successfully obtaining interference fringes. On March 21, both Nanshan Station and Tianma Station participated in EVN gr039 observations, with Nanshan Station simultaneously recording using both DBBC2 and ABBC equipment. After the experiment, data from the same time period was correlated with Shanghai

Tianma Station, with processing results shown in Figure 5. Figure 5(a) shows the DBBC2 test results, while Figure 5(b) shows the ABBC test results, demonstrating that the DBBC2 results are significantly better than ABBC. On April 3, Nanshan Station conducted K-band fringe detection experiments with Tianma Station and obtained good test results, as shown in Figure 6. These domestic and international joint test results indicate that the DBBC2 system at Nanshan Station has been successfully established.

5.5 Problems Encountered During Upgrade

(1) The DBBC2 rear panel does not have a designed VSI connection port, so the VSI cable connected inside DBBC2 requires some additional fixing.

(2) Upon receiving the equipment, the connection plugs and sockets between the FILAIN, ADB1/2, CORE, and FILAOUT circuit boards inside the chassis were all disconnected. After connecting all board interfaces and verifying they were correct, power-on operation revealed that the software could not load, and the cause could not be determined from the equipment indicator lights. After analysis and troubleshooting, the reason for software loading failure was determined to be insufficiently tight connections between the plugs and sockets of the various circuit boards. After securing them tightly, the software loaded normally.

(3) In the initial tests, the signal-to-noise ratio of the correlated processed signals was found to be relatively low, which was initially suspected to be caused by low input signal amplitude. However, increasing the signal amplitude at the DBBC2 input did not improve the correlation results. Through repeated analysis and testing, it was discovered that the DBBC2 input signal amplitude should actually be reduced, as the signal entering DBBC2 was already approaching saturation. This represents a key difference between DBBC2 and both ABBC and CDAS (Chinese Data Acquisition System) regarding input signal amplitude.

6 DBBC2 IF Wiring Distribution

After all DBBC2 tests are normal, the newly established system can participate in formal international and domestic joint observations. However, it is necessary to provide the IF connection diagram of the station's receiver signals on DBBC2 to relevant personnel who create observation schedules. They formulate the station' s observation mode and specific BBC allocation based on the wiring diagram provided by the station. Figure 7 [Figure 7: see original paper] shows the DBBC2 IF wiring diagram at Nanshan Station.

7 Conclusion

With the development of very large scale integrated circuits and software radio technology, broadband digital recording terminals—Digital Base Band Converters (DBBC)—have gradually replaced analog recording terminals (ABBC) worldwide. Compared with analog equipment, DBBC offers better cost-performance ratio, superior passband characteristics, and better stability and reliability indicators [11]. After comprehensive testing of the DBBC2 system installed at Nanshan Station, all technical indicators have been proven to meet expected requirements. Analysis of joint test results with major domestic and international stations demonstrates that its performance is superior to the original analog baseband converter. In terms of practical operation, this system is also more convenient than the analog baseband converter. The successful establishment of the DBBC2 system at Nanshan Station marks the complete end of the global VLBI analog baseband converter era. It is foreseeable that the DBBC2 system at Nanshan Station will play an even greater role in future VLBI joint observations.

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Note: Figure translations are in progress. See original paper for figures.