PROCEEDINGS OF SCIENCE

Probing high resolution spectroscopy with the Digital BBC VLBI-backend

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We present a feasibility study, to use the VLBI backend DBBC at the 100 m Effelsberg radio telescope for spectroscopic observations. The digital Base Band Converter (DBBC) allows to record Nyquist-sampled base band data, enabling recording of truly high-resolution spectra. We successfully developed software to read, process, and calibrate VLBI Mark5B-format data from the DBBC and therewith produced calibrated astronomical spectra. For comparison simultaneous measurements with the well established FFT spectrometer were taken, which agree well with the DBBC spectra. In addition, by cross-correlation of the two orthogonal polarizations, spectra of the linear polarization were calculated from the VLBI data. The final calibration of the polarimetric data is still under development, but spectro-polarimetry with the DBBC will be a welcomed feature as this is currently not possible with the FFT spectrometers at Effelsberg.

12th European VLBI Network Symposium and Users Meeting
7-10 October 2014
Cagliari, Italy

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PoS(EVN 2014)070

1. Introdution

To perform spectroscopic observations the 100 m Effelsberg antenna is equipped with a number of state-of-the-art Fast Fourier Transform Spectrometers (FFTS, [1]). They are available in different configurations and provide between 32k and 64k channels over a bandwidth range of 50 MHz to 2500 MHz. As a reference for the comparison with the VLBI backend, we used the XFFTS with 32k channels and 100 MHz band width.

With the installation of the new digital Base Band Converter (DBBC) it became evident that with some software the DBBC could be used as spectrometer as well. The DBBC is composed of 4 IF sampling modules that process an input band-width of 500 MHz. In its down converter mode each IF module is connected to an FPGA board that computes 4 USB+LSB base band channels at bandwidth between 1 to 16 MHz ([2]). The Mark5 data recording system is optimized for wide band width and efficient data storage and therefore the data is recorded at 2-bit quantization levels. As this highly reduces the dynamic range the quantization threshold is continuously adjusted to better sample the input signal. During this process the total power information of the recorded time series data is lost. To overcome this, the DBBC measures the total power level every second from the initially 8-bit sampled data. For the calibration of the system temperature, the noise diode of the receiver is switched at a rate of 80 Hz during the observations. Therefore, one receives two total power values each second; 500 ms of $T_{\mathtt{sys+Tcal}}$, 500 ms of $T_{\mathtt{sys}}$.

2. Observing Strategy

The first measurements were done with both backends in parallel. The antenna performed standard position-switch observations using the FFTS and the DBBC recording in piggy-back mode. Thus data is taken under identical conditions, e.g. weather, focus, and pointing, to allow direct comparison. Our target was the OH maser in the W3 cloud and the observations were performed at 18-cm wavelength. Since the maser is strong and is known to have a significant amount of structure, this would allow to test the potential use of the higher resolution that is expected from the DBBC spectra. The DBBC recorded two 16 MHz wide USB channels at left and right circular polarization resulting in a data rate of 32 MB/s.

3. Data Reduction and Calibration

For further analysis the VLBI data from the Mark5 diskpack was copied to a local disk. Software to read in, process and calibrate the Mark5 data was written within this project ([3]). The reduction includes the following steps:

- Search for ON and OFF source periods.
- Read and decode portions of the data. Reading all data at once would consume too much memory.
- Identify the noise diodes switching cycle from the data.

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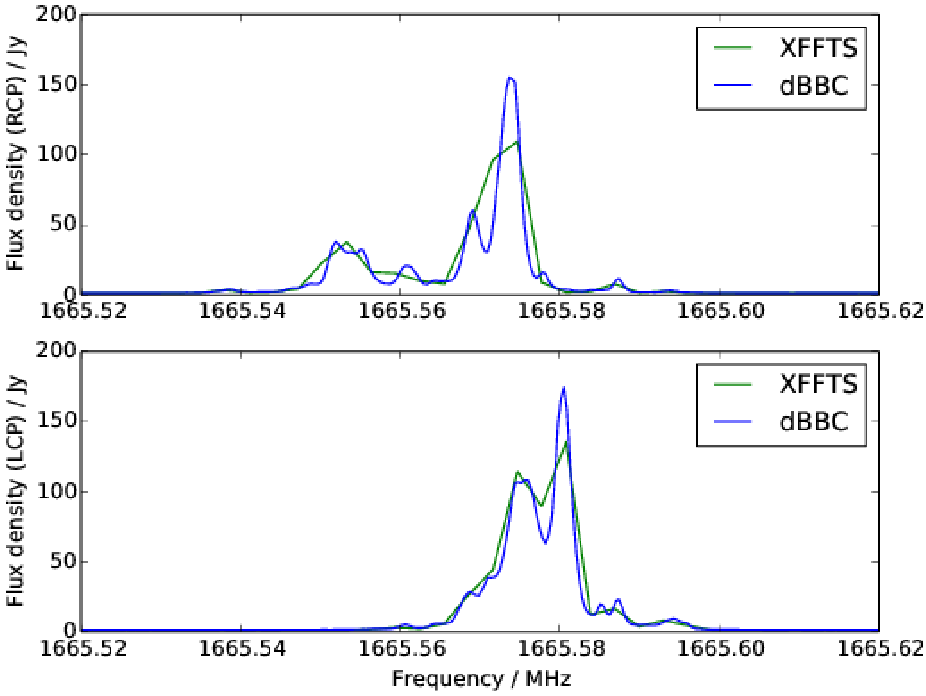

Figure 1: Resulting spectra of the OH maser of W3 from the XFFTS and DBBC data in RCP and LCP. The resolutions are 3.05 kHz/Ch for the XFFTS and 0.38 kHz/Ch for the DBBC. They show comparable amplitudes, but the increased resolution of the DBBC shows a lot more maser features.

- Combine the time series data with the total power measurements from the DBBC log-file by scaling the normalized 2-bit data with the square-root of the power.
- Calculate the power spectra via a Fast Fourier transformation. The FFT is calculated piecewise for the chosen number of channels using the necessary number of blocks (few hundreds) from the time series. The individual blocks are averaged to obtain the final spectra.

For subsequent flux calibration, we follow the procedures described in B. Winkel et al. ([4]), which accounts for the frequency-dependence of receiver gain and system/noise diode temperature.

4. Results

The resulting spectra are shown in Fig. 1. The DBBC spectra were processed with about ten times higher resolution than the one provided by the XFFTS, 0.38 kHz/Ch for the DBBC and 3.05 kHz/Ch for the XFFTS. The higher resolution spectra obtained from DBBC data reveal a lot of new features that are not seen with the XFFTS data. DBBC spectra at even higher resolution did not reveal any additional components for the W3 OH maser. The calibration of the DBBC and XFFTS spectra is in good agreement. The integrated flux density of the XFFTS and DBBC spectra on continuum and line sources agree within $\sim 5\%$. Both data sets show comparable noise.

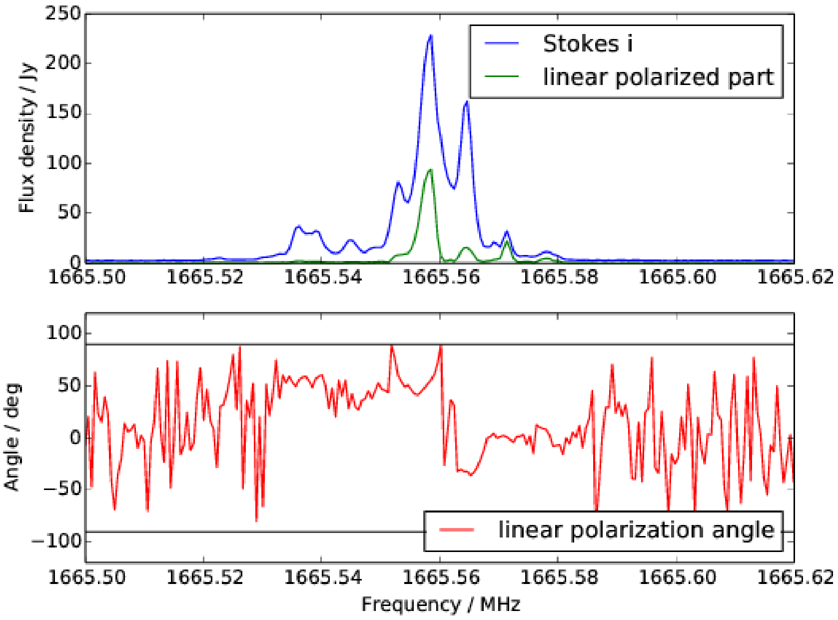

Figure 2: Only with the DBBC one can calculate the linear polarization properties of the spectrum. The top panel shows the linear polarization intensity and the lower panel the polarization angle. The polarization angle is only defined in regions with polarized intensity and its orientation is not absolutely calibrated yet.

Since the DBBC records the phase of the incoming wave, it is possible to obtain the full Stokes parameters and calculate polarization properties (Fig. 2). This is not possible with the current FFT spectrometer. The polarization calibration of the spectral line data is still in progress, but tests on continuum sources with known polarization properties have shown that it is possible to calibrate the DBBC data for polarization.

Our results are promising and demonstrate that high-quality spectra in full polarization can be obtained with the DBBC. To further improve the calibration, the next firmware will contain a mode to record DBBC data at full 8-bit resolution of the first ADC which should allow a better and easier calibration procedure.

References

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