Gino Tuccari et al.: e-NRTV – Radar VLBI Network LFVN, IVS 2006 General Meeting Proceedings, p.236–240
http://ivscc.gsfc.nasa.gov/publications/gm2006/tuccari2

e-NRTV – Radar VLBI Network LFVN

Gino Tuccari [1], Igor Molotov [2], Alexander Volvach [3], Alexander Konovalenko [4], Alexander Dementiev [5], Liu Xiang [6], Yuri Gorshenkov [7], Maria Nechaeva [5], Igor Falkovich [4], Alexander Pushkarev [2], Vladmir Samodurov [8], Alexander Antipenko [5], Nikolay Dugin [5], Salvatore Buttaccio [1], Gaetano Nicotra [1], Ivan Strepka [3], Vladimir Titenko [2], Vladimir Jazykov [2]

1) *INAF, Istituto di Radioastronomia*
2) *Central Astronomical Observatory at Pulkovo, RAS*
3) *Lab. Radio Astronomy of Crimean Astrophysical Observatory*
4) *Institute of Radio Astronomy, NASU*
5) *Radiophysical Research Institute*
6) *Urumqi Astronomical Observatory*
7) *Special Research Bureau of Moscow Power Engineering Institute*
8) *Puschino Radio Astronomy Observatory of Lebedev Physical Institute, RAS*

Contact author: Gino Tuccari, e-mail: `g.tuccari@ira.inaf.it`

Abstract

The Near Real Time Radar VLBI Network LFVN is progressively increasing its performance and processing structures. Dedicated acquisition and recording NRTV terminals are placed at Bear Lakes (Russia), Noto (Italy), Simeiz (Ukraine), Evpatoria (Ukraine), Urumqi (China). A new, entirely digital terminal has been developed for this network, and two units will be placed at two radiotelescopes in 2006. A collaboration program is under development with the European Space Operations Center and the Ballistic Center of the Keldysh Institute of Applied Mathematics, and two VLBI sessions were carried out in 2005. The first experiment was in September for VLBI radar research of the small space debris fragments, the second experiment was in October for differential VLBI measurements of the Mars-Express interplanetary spacecraft position. A new dedicated software correlator is under development for a distributed correlation process. The more recent scientific results are reported. The VLBI fringes were received and fringe rates were measured for radar echo-signals of Moon, Venus and space debris objects on baselines involving the stations at Noto, Bear Lakes, Simeiz, and Urumqi.

1. Introduction

LFVN was initiated in 1996 under INTAS project 96-0183 to involve Russian and Indian radio telescopes in VLBI activities [1]. First observations were carried out with the help of Mk-2 terminals and the JPL/Caltech Block II correlator. Then it continued with a series of solar wind radio wave experiments arranged jointly with DSN. The Canadian S2 system and DRAO, Penticton, S2 correlator were used during the next stage of the project that allowed receiving the first LFVN images of AGN. The NRTV Internet based acquisition, transfer and correlation system has been used since 2003 in investigating the Solar system bodies with new VLBI radar techniques. In 2005, the first LFVN delta-VLBI run for Mars-Express interplanetary mission continued the series of the earlier spacecraft navigation experiments that were processed with NIRFI correlator in N. Novgorod. After the beginning of limited operations of the NIRFI-3 correlator and the NRTV correlator in Noto, the LFVN completed the last necessary part of a VLBI network, having already available a set of radio telescopes collaborating for observations, scheduling and post-processing groups, and a technology development team. Today a new, entirely digital back-end system has been elaborated and a new dedicated NRTV software correlator is under development for a distributed correlation process.

2. e-NRTV and rDBBC

The e-NRTV Internet based acquisition, transfer and correlation system provides a maximum recorded signal bandwidth of 48 MHz, flexibly scalable up to few kilohertz. The system is based on 1 or 2 bit sampling at base band level, with further data packing and recording to PC-disk as files through a dedicated board, and has a possibility to transfer the full amount or portion of VLBI data in near real time to a correlator, using a standard Internet connection [2]. NRTV-terminals are currently installed at Noto, Bear Lakes, Urumqi, Simeiz, and Evpatoria. Other terminals will be installed in Puschino or Staraya Pustyn (Russia). During 2005 a GPS receiver was integrated to NRTV-terminals in order to simplify the synchronization of the recorded VLBI data.

A new backend system has been defined for the Radar VLBI network operating with an improved e-NRTV recording terminal. Such processor, named rDBBC is able to translate the RF or IF portion of band, where the radar echo is expected, to the recorder. 1 narrow band is used most of the time, but the terminal is able to handle portions of bands from 125 KHz up to 16 MHz. The terminal is integrated with the recorder and managed even remotely, so that the frequency settings, output modes, and the recording can be operated from a central point for the entire network. Input band is 128 MHz, spanning from 0.1 MHz up to 2.4 GHz, so that S band is directly down converted. Any other higher observing bansd need then to be converted in any portion of this wide interval. A very compact VLBI terminal is so obtained in a 'single box', having as input the sky RF (below 2.4 GHz) and as output the network connection, for both managing the system and data transfer. When the net connection is not fast enough, the disk recording acts as an elementary buffer.

The three main elements are then connected to from a single system, a digital data processor, a digital disk recorder, an industrial PC. External elements are: a NMEA GPS receiver with serial connection, H-Maser clock and 1PPS, RF coming from the antenna.

A new dedicated software correlator is under development, sharing more processes among different PC platforms and being baseline dependent. A simplification and correlation time reduction will come from the introduction of an initial preprocessing in the acquisition station before sending data to the correlator. The preprocessing step is performed within the acquisition computer taking into account an input file containing the a-priory expected frequency of the echo signals. A complex FFT is performed with high frequency resolution (0.015 Hz) and only data around the useful signal are kept to be transferred for correlation. The total data reduction can achieve a factor of 1000:1 depending on the echo frequency spread.

3. Solar Wind VLBI - Radio Sounding of Circumsolar Plasma

A series of experiments on VLBI radio probing of solar wind plasma was carried out at C, L and P bands from 1998-2005. A VLBI array received the radio emission of extragalactic sources located at different angular distances from the Sun (3-130°) after propagation through the turbulent circumsolar plasma. Correlation of recorded data was carried out in Penticton with NIRFI-3

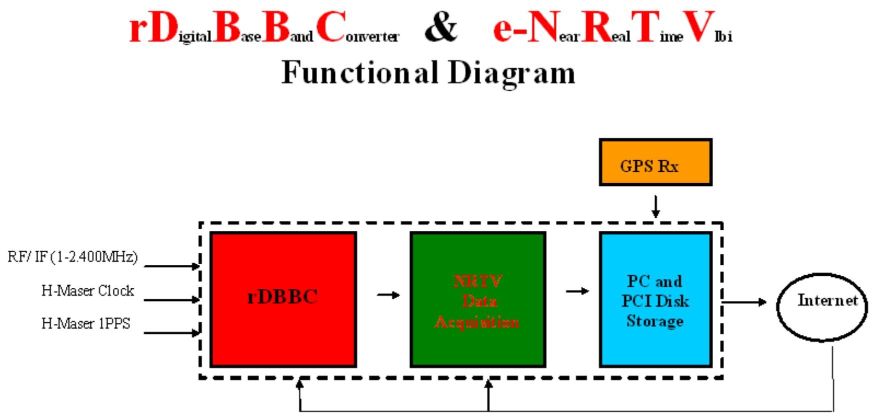

Figure 1. Data acquisition flow. IF coming from the receiver is down-converted using the rDBBC converter operating in the range 0.1-2.400 MHz, where two data channels of variable bandwidth are selected to be transferred to the Data Acquisition module. One or two bit data are stored on disk and sent through the Internet. Time synchronization is assured by a dedicated GPS receiver. The terminal is set through the Internet connection for fully remote operations.

processors. Value of solar wind velocity V and an index of spatial spectrum of electron density fluctuations p could be obtained by a spectral analysis of the correlated signals [1]. Distribution of large-scale intensive irregularities of electron density is derived from the variations of spectrum's width, and distribution of the weak small-scale irregularities may be understood from the spectrum "wings" shapes. The L-band INTAS00.3 experiment (Bear Lakes RT-64, Noto RT-32, GMRT-45, HartRAO RT-26, Shanghai RT-25, Puschino RT-22) allowed to measure the values of V and p from observations of 6 sources on 3 baselines: Bear Lakes–HartRAO, Bear Lakes–Noto, Noto–HartRAO. Figure 2 demonstrates the samples of power spectrums of the interferometry response on the $1514-241$ source emission located at angular distance of 14 degrees from the Sun. Velocity of solar wind was determined by frequency f of spectrum break points according to the expression $f = V/\rho$ (ρ - baseline projection on wave-front). The average value of solar wind was estimated as $V = 342 \pm 17$ Km/s. Evaluations of the spectral index p were carried out according to the slope of the interferometer signal spectrum. The average value of the spectral index p is equal to $p = 357 \pm 0.006$. It is the first time that the parameters V and p were evaluated independently of irregularities scales, comparable with baseline lengths from 2000 to 9000 km. The obtained results confirmed the adaptability of the "freezing-in hypothesis" and Kolmogorov power spectrum for the description of spatio-temporal variations in solar wind on large distances from the Sun $R > 40R\odot$ ($R\odot$ - solar radius).

4. AGN Results of INTAS00.3 Experiment

The INTAS00.3 experiment lasted about 50 hours in period 28.11.99 - 01.12.99 at left-circular polarization. Each source was observed in 5–6 scans of 30 minutes. The VLBI data of 8 MHz bandwidth with 1-bit sampling was recorded using the Canadian S2 system and then correlated in Penticton at 256 spectral channels, each 31.25 kHz with 2 s integration time for AGNs and 0.1 s

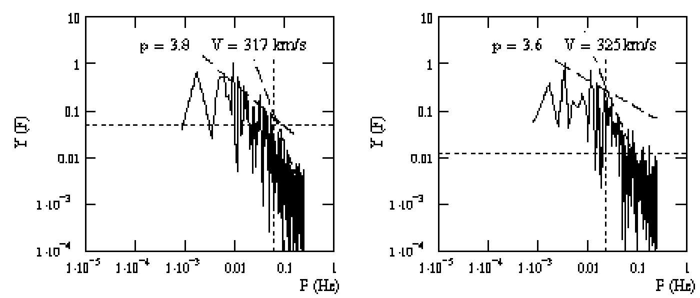

Figure 2. 1514-241 source interferometry signal power spectrums on Bear Lakes-Noto (left side) and Bear Lakes-HartRAO (right side) baselines

for solar wind sources. The data analysis, editing, and calibration were done using standard AIPS procedures. Gain curves and system temperatures measured for each participating antenna were used for amplitude calibration of the VLBI data. The primary phase calibration was done using the AIPS task FRING with 120 s coherent integration time, with subsequent phase corrections for the residual delays for the entire time of the experiment using Bear Lakes as the reference antenna. The imaging was performed in DIFMAP. A point source at the phase center was applied for the initial models in the hybrid mapping. Figure 3 presents constructed VLBI LL-images of BL Lac object 1418+546 ($z = 0.152$) and a quasar CTA 102 ($z = 1.037$). Both sources revealed one-sided core-jet structure (because of Doppler boosting) with a position angle of 120° and 145°, and with estimated brightness temperatures of $1.3 \cdot 10^{12} K$ and $5.9 \cdot 10^{12} K$ for 1418+546 and CTA 102, respectively.

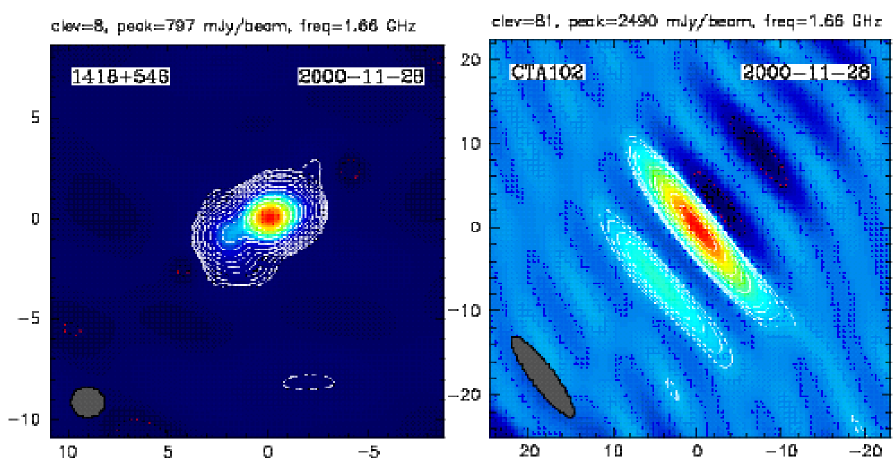

Figure 3. 1.66 GHz LFVN maps of 1418+546 and CTA 102. The lowest contours are drawn at levels of 1% of the peak value of 797 mJy/beam and 3.25% of the peak value of 2490 mJy/beam for 1418+546 and CTA 102, respectively. Axes are given in mas.

5. VLBR05.1 and MEX_053 deltaVLBI Experiments

The delta-VLBI technique allows to link the sky position of a measured object with the position of a close ICRF quasar on the celestial sphere to reconstruct the orbit of an object in the Radio Reference Frame. The series of delta-VLBI runs were carried out from 1984 to 1993 for the Venus-15, Vega-1, 2 and Phobos-1, 2 interplanetary stations, Astron and Granat high-apogee spacecrafts. Since 1999 the differential VLBI radar (VLBR) method is under development using a C-band transmitter at Evpatoria to radio-sound space objects. VLBR05.1 run, which was conducted out at C-band in period 10.09.05-16.09.05 with participation of Evpatoria, Bear Lakes, Simeiz, Urumqi and Puschino, continued the row of the trial VLBR observations of space debris objects, Moon, Venus and Mars to adjust the procedure of VLBI fringes obtained for radar echo signals. The received Doppler and fringe rate measurements are used at the Keldysh Institute of Applied Mathematics, RAS (see examples of VLBR measurements in Figures 4). The beginning of collaboration with the European Space Operations Center allowed to renew the experience of the classic delta-VLBI with Mars-Express interplanetary spacecraft. The first results of the MEX_053 experiment that was carried out at S/X-band in 09.10.05-11.09.05 with participating stations Evpatoria, Bear Lakes, Simeiz and Urumqi are presented in Figure 5.

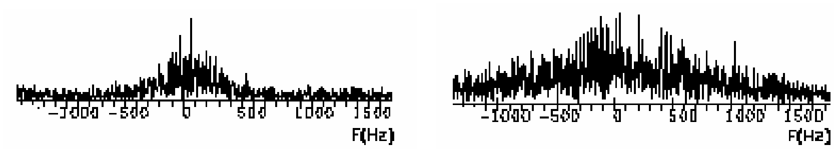

Figure 4. The VLBI fringes for C-band (5010.024 MHz) echo-signals reflected by the Moon on baselines Bear Lakes–Noto (left side) and Noto–Simeiz (right side), 2004, September, 9, 23:10:56 and 23:11:50, measured fringe rates respectively: 2160.001 Hz and -1999.249 Hz, VLBR04.3.

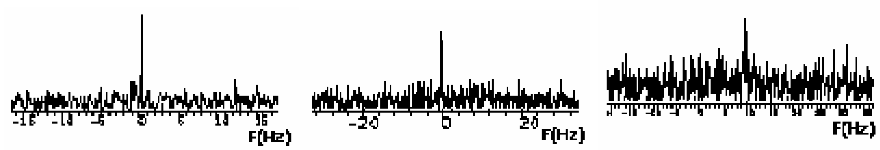

Figure 5. The VLBI fringes for Mars-Express S-band (2296.482 MHz) signal on baselines (from left to right) Bear Lakes–Evpatoria, Evpatoria–Urumqi, Urumqi–Bear Lakes, 2005, October, 10, 19:30:20, measured fringe rates respectively: 523.812 Hz, 1693.110 Hz, 1693.1797 Hz, MEX_053.

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[2] G. Tuccari et al., E-LFVN - An Internet Based VLBI Network In: Proceedings of the 7th European VLBI Network Symposium, eds. R. Bachiller et al., October 12-15, Toledo, Spain, 331–332, 2004.