The New Generation Russian VLBI Network

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Abstract

This paper deals with a new project of the Russian VLBI Network dedicated for Universal Time determinations in quasi on-line mode. The basic principles of the network design and location of antennas are explained. Variants of constructing receiving devices, digital data acquisition system, and phase calibration system are specially considered. The frequency ranges and expected values of noise temperature are given.

1. Introduction

Since 2006 the radio astronomical observatories of the VLBI Network "Quasar" have actively participated in both international and national programs of observations. In 2008–2009 essential upgrade and development of the "Quasar" Network was performed including replacement of gear and pointing system electronics, modernization of frequency and time keeping system, replacement of data acquisition and data recording systems [1]. All observatories were linked by optical fiber lines, providing operational determinations of Universal Time from 1-hour sessions in e-VLBI mode. In 2010–2011 further modernization of the Network "Quasar" will include co-location of radio telescopes with "Sazhen-TM" SLR system and combined GPS/GLONASS/Galileo receivers at the observatories.

Further development of the GLONASS navigation system puts forward higher requirements to its fundamental segment particularly in maintenance of celestial and earth fixed coordinate systems and in monitoring the Earth orientation parameters in real time mode. Moreover, the Russian VLBI Network gives the unique possibility for quasi on-line determinations of Universal Time for supporting GLONASS. According to these requirements the design of a new generation Russian VLBI Network has been initiated.

2. Design Principles

The following principles are assumed as a basis of the new generation Russian VLBI Network:
- The network should have maximum longitudinal separation of sites for precise determination of Universal Time;
- Equipment of observatories should be compatible with the VLBI2010 system and that of the "Quasar" Network;
- Infrastructure of new observatories should be similar to the one of the "Quasar" Network.

The supposed geometry of the new VLBI Network is presented in Figure 1. The largest baseline of the new VLBI Network is more than 1.5 times larger than that of the "Quasar" Network. All the sites have good infrastructure, optical fiber communication lines, and comparatively good radio

climate with low level of radio interference. The specific features of a radio telescope of the new Network will be described below.
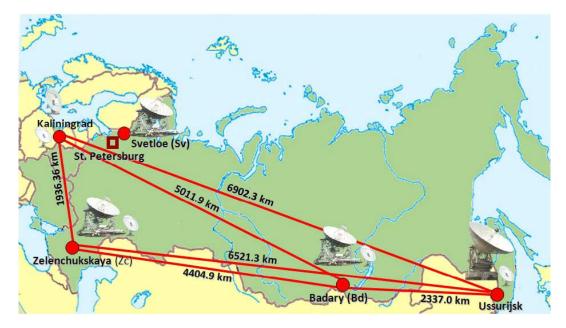

Figure 1. Proposed location of sites of the new generation Russian VLBI Network.

3. Front-end

Typical configuration of a VLBI site includes an antenna equipped with receivers for 2–14 GHz band. The reception of radio signals should be fulfilled not in the whole range 2–14 GHz, but in several sub-bands (Figure 2). Such a solution arises from the requirement to have two circular polarizations in S/X bands and to avoid an interference at different radio frequencies. A block-diagram of the new receiver is shown in Figure 3.
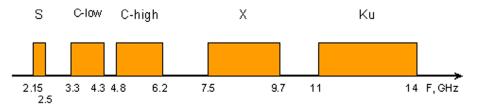

Figure 2. Working frequency bands for the new generation Russian VLBI Network.

The output signals from receivers should be processed by digital signal processing (DSP) units, recorded to disk modules and transmitted through optical fiber lines.

It is suggested to use relatively lightweight 12-meter antennas with fast slew rates. We are considering the options of either constructing such an antenna in Russia or purchasing an existing communication antenna.
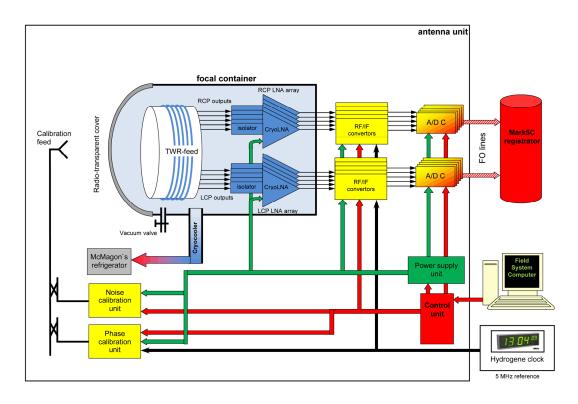
Figure 3. Block diagram of radio telescope for the new generation Russian VLBI Network.

An assembly of receiver and feed will be placed in the primary focus of the antenna. It is considered to use a circular travelling-wave-resonator (TWR) antenna as a feed. The TWR antenna should be cooled by a cryogenic system to 20 K level, and the heat shield to 80 K level. The low noise amplifiers should be cooled down to 20 K, and their gain should be about 30 dB. The total system noise temperature is expected to be 16–20 K (Table 1).

Table 1. The expected system noise temperature.

Band	System Noise Temperature
S	16 K
C-low	16 K
C-high	17 K
X	18 K
Ku	20 K

4. Digital DAS

The new generation digital data acquisition system (DAS) consists of a 10-channel RF/IF down converter and four identical DSP units (Figure 4). The RF/IF down converter transforms the input signal spectrum from a multi-band TWR antenna of the radio telescope (C, X, S, and

Ku bands) to IF range of 1–2 GHz. Eight out of the ten channels of the RF/IF down converter can be tuned in the wide frequency range of 3–14 GHz. There is no down conversion in the remaining two channels intended for S-band because it can be directly digitized by analog digital converter (ADC), but the signal is amplified and filtered. Each DSP unit can be connected to the outputs of RF/IF down converter through IF switch. Each channel of the DAS requires one Mark 5C. As the DAS is located on the antenna, the signal is transmitted to the control room by an optical fiber line in digital form.
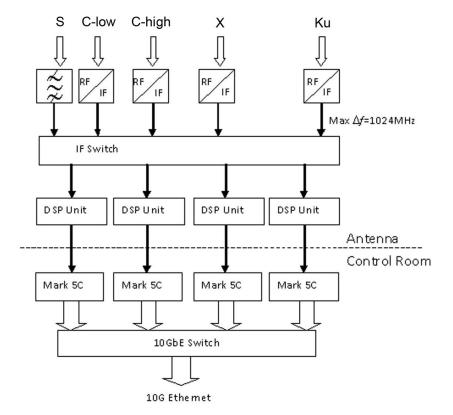
Figure 4. The Digital Data Acquisition System for the new generation Russian VLBI Network.

The DSP unit is the basis of the DAS and contains: ADC, field programmed gate array (FPGA), clock oscillator, demultiplexer of the ADC output signal, flash RAM to store FPGA firmware, microcontroller, and optical transmitters.

It will be implemented as a single multilayer printed circuit board (PCB).

The FPGA is the basis of the DSP unit. It performs the measurement of an RMS level of the input signal, 2-bit quantization of output signals, generation of a test vector to check a transmission line and data recording system, formatting the output data in accordance with a data recording system interface and sending them to the optical transmitters.

The prototype of the DSP unit was made to check the basic principles. It consists of evaluation boards of the 10-bits ADC (AT84AS008-EB) and FPGA XC5VFX70T (ML507).

The tests of the prototype provided an opportunity to implement the digital DAS with modern electronic components.

5. Phase Calibration

A phase calibration system is under development. The main purpose of the phase calibration system is to monitor the instrumental delay of receiver and data acquisition equipments. A special pulse generator is suggested to be used as the main component of the phase calibration system. A spectrally pure 5 MHz signal is transmitted by cable to the receiver, where it is converted to a 1 MHz signal which makes a charge-storage diode to generate pulses of very short ($\approx$ 30 ps) duration (Figure 5).
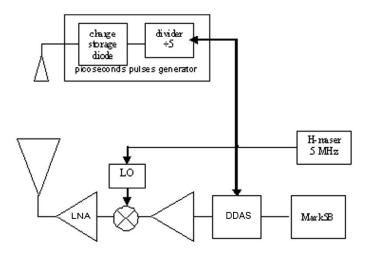

Figure 5. The phase calibration system for the new VLBI Network.

The possibility of locating the phase calibration injection point ahead of the horn is studied. Phase calibration impulses are radiated from a special broadband feed fixed on one of the legs supporting the focal box. To meet the requirement of a distant radiation zone the feed is to be placed at a point far away from a mirror. The key advantage of such a system is that the horn and all the following devices are included into the phase calibration loop.

The prototype of a transverse electromagnetic (TEM) horn with TEM double-ridged transition for 2–14 GHz frequency has already been made at IAA RAS and is being tested now. The prototype parameters measured prove the possibility of using this feed for phase calibration.

Coaxial cables connecting the H-maser and the pulse generator are selected taking into account the low temperature coefficient and mechanical stress sensitivities. For the LMR type cable the temperature coefficient is about 10 ppm/K. If 10 meters of this cable are exposed to significant temperature fluctuations, its stability should be under 0.3 ps/K. Typical cable length change with a 360° wrap on 4 inch radius is under 1 ps. So, in this case a cable measurement system is not required.

References

[1] Finkelstein A., Ipatov A., Smolentsev S., The Network "Quasar": 2008–2011, Proc. 5th IVS General Meeting, 39–46, 2008.