WVRs for the “Quasar” Network

G. Ilin, V. Bykov, V. Stempkovsky, A. Shishikin

Abstract A prototype for dual frequency water vapor radiometers (WVRs) was developed at IAA and tested at the “Svetloe” observatory for more than a year. It was constructed according to the IAA plan to have near real time information about the zenith tropospheric wet delay (ZWD) in “Quasar” network observatories for use in VLBI data processing. Another two WVRs of the same type will be constructed in 2014 for the “Badary” and “Zelenchukskaya” observatories. The WVR prototype demonstrated very stable metrological characteristics in time intervals of several months. The values of ZWD assessed by WVR were compared with the same values determined from GNSS observations. The difference between the GNSS and WVR ZWDs is practically equal to zero with an accuracy of up to 3–5 mm (r.m.s), except for periods of intensive rain. This result was achieved due to precise measurements of the atmosphere brightness temperature.

Keywords Water vapor radiometers, wet delay

1 Introduction

IAA is realizing a special program to equip the “Quasar” VLBI Network observatories with WVRs. WVRs are designed for rapid evaluation of troposphere parameters. ZWD measured by WVR will be used in data processing of VLBI observations. We hope that WVRs will be very useful additional instruments for “Quasar” co-location sites [1], applied for determination and monitoring of ZWD and integrated water vapor (IWV) practically in real time mode.

Institute of Applied Astronomy of RAS

2 WVR Design

For effective application of the ZWD in VLBI data processing, it is necessary to measure it with maximum accuracy, up to 3 mm (r.m.s.). To solve this problem, WVRs should measure atmosphere brightness temperatures most accurately.

To realize this in regular automatic observations, WVR equipment must satisfy the following requirements:

- very stable microwave reference sources;
- maximum temperature stability of all RF units;
- temperature control (and logging) of all critical points;
- total gain variation control of the RF units;
- operation mode: “total power” + fast switching ($\sim$1 kHz) of input signals;
- guaranteed linearity of square law detector;
- reliable electronic unit;
- remote access and control facilities.

We tried to realize these requirements in the modern WVR design.

Two WVR models have been tested at the “Svetloe” observatory. WVR1 was installed in 2011, and WVR2 was installed in June 2013. The WVRs are operating in different modes. WVR1 is fully steerable to have the capability of following radio telescope RT-32. WVR2 is fixed and looks only at the zenith direction. The WVR3 model is designed for installation at the “Badary” and “Zelenchukskaya” observatories.

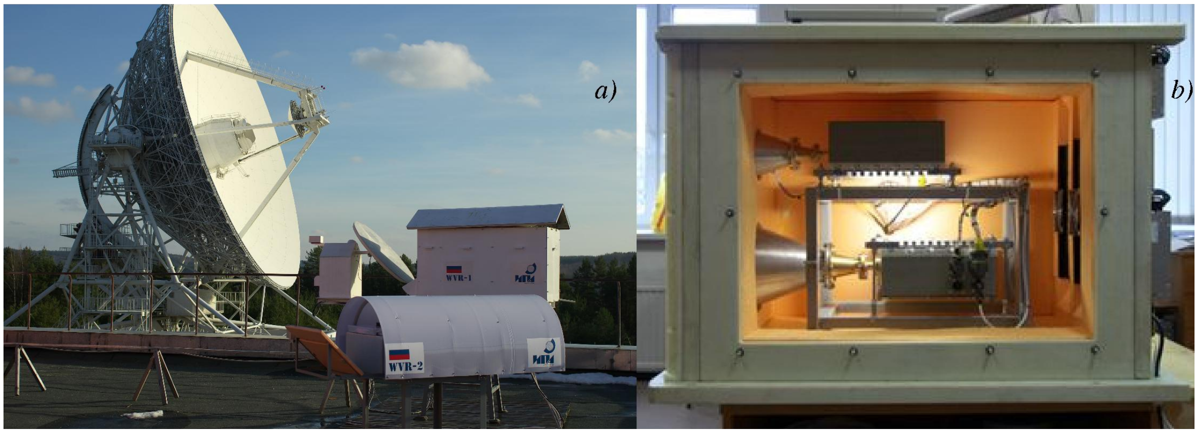

Fig. 1 (a) WVRs’ location at the “Svetloe” observatory. (b) General view of the WVR3 box in a laboratory test board.

It will be fully steerable and capable of moving synchronously with the new RT-13 radio telescope.

WVR1 and WVR2 are located at the “Svetloe” observatory on the roof of the laboratory building at a distance of about 100 m from RT-32. A general view of the WVRs’ location is shown in Figure 1a.

The construction of all WVR models is based on the ideas proposed in [2]. In the literature, this radiometer design is better known as absolutely stable radiometer [3].

WVR has two unified-in-design microwave radiometric blocks placed into the thermo-stabilized ($+30 \pm 0.1$°C) container. Each radiometric block has two internal waveguide-matched loads stabilized at a temperature of $+35 \pm 0.01$°C and $+60 \pm 0.01$°C. These loads are used as very stable reference signal sources [4]. All microwave units of radiometric blocks are placed on a thermostatic platform ($+30 \pm 0.01$°C). Radiometric blocks are equipped with horn-lens antennas. A general view of the WVR3 design is presented in Figure 1b. Specifications of the WVR are listed in Table 1.

Reference signals of WVR1 were calibrated with the tipping calibration method (tipcal) [5]. Tipcal was done exclusively in perfect weather conditions for determination of reference signal and atmosphere brightness temperature with a maximum accuracy.

As a calibration signal (T_{kA}) for the WVR, we use the combination of receiver noise signal ($T_{rec.A}$) and reference signal of “cold” waveguide matched load (T_{cA}) stabilized at a temperature of $+35 \pm 0.01$°C:

$$T_{kA} = T_{cA} + T_{rec.A}(t_{amb})$$

Table 1 Specifications of the WVR3.

Specifications:	Value
Frequency bandwidth 3 dB, GHz	
Channel A	20.7 ± 0.25
Channel B	31.4 ± 0.25
Receiver noise temperature, at the input, K,	
Channel A	150
Channel B	280
Gain, up to *Sq*. law detector, dB	
Channel A	65
Channel B	65
Brightness temper. sensitivity, K, $t = 1s$ (dry weather)	
Channel A	0.012
Channel B	0.025
Relative gain instability, 24 h, %, less than	0.03
HPBW(-3dB) / BW(-35dB)	$6°/22°$
Angular resolution Az, El, arc min.	5

The presence of small losses of the lens material leads to dependence of the receiver noise temperature on the value of ambient temperature (t_{amb}). This dependence was found and measured due to high accuracy of tipcal, made during the period of a year when t_{amb} changed from -20°C to $+20$°C. Temperature dependence of calibration signals was used in the data processing.

In the WVR3 model, we will apply more effective thermal isolation of the microwave units of the radiometric blocks to reduce the temperature dependence of the calibration signals or the temperature dependence of the receiver noise temperature.

The parameters of the WVR1 calibration signals are presented in Table 2.

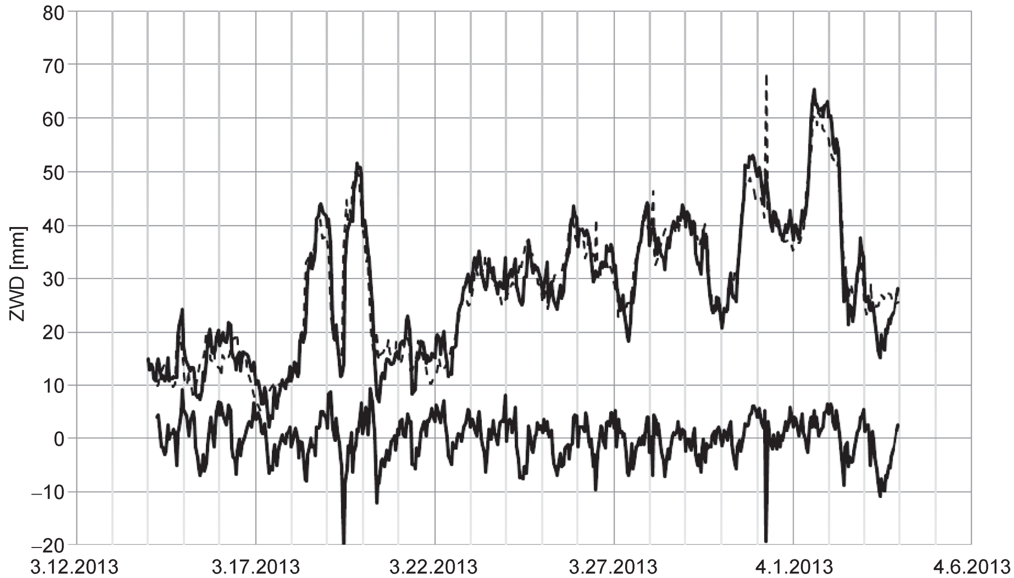

Fig. 2 ZWD, in mm, estimated by WVR1 (dashed line), retrieved from GNSS (solid line), and their difference (lower line).

Table 2 Parameters of WVR1 calibration signals.

Stability of the reference signal ("cold" loads), K, 1.5 year interval	
Channel A	313.02 ± 0.02
Channel B	313.38 ± 0.02
Effective noise temperature of the calibration signals, K, $t_{amb} = 0°C$	
Channel A	443.8
Channel B	571.0
Stability of the calibration signals (temperature dependence is excluded, K, (r.m.s.)	
Channel A	0.3
Channel B	0.4

3 Results

The retrieval of ZWD from the brightness temperatures measured by WVR proceeds as follows. First, an IWV value (g/cm^2) is determined, and ZWD (cm) can be calculated as [6]:

$$ZWD = (0.106 + 1722/T_{eff}) \cdot IWV,$$

where T_{eff} is the atmosphere mean temperature (K), calculated from radiosonde data, and can be modeled as a linear dependence on surface temperature. Now, at the "Svetloe" observatory T_{eff} can be measured by temperature profiler MTP-5 [7].

To estimate the accuracy of the retrieval algorithm, we compared ZWDs estimated by WVR1 with those from GNSS observations for the same time period. These values for a "dry" period from March–April 2013 are presented in Figure 2. Their difference is better than 3 mm (r.m.s.), when excluding two peaks associated with precipitation.

For a longer interval—from several months to one year—the standard deviation of the ZWD difference increases to 5 mm (incorrect WVR1 data for periods of rainfall are excluded).

4 Conclusions and Future Plans

WVR1 and WVR2 have shown stable metrological parameters and reliable, maintenance-free operation for intervals of more than six months.

The WVR3 model accumulates all the positive technological experience and will be more stable in operation under unfavorable weather conditions.

WVR3 models will be installed at the "Zelenchukskaya" and "Badary" observatories at the end of 2014. We also plan to install MTP-5 at "Zelenchukskaya" during May 2014. The data obtained by MTR-5 will be used in WVR data processing.

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