Dual Channel Water Vapour Radiometer Development

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A new instrument for measuring the atmospheric water vapour is being developed at the Onsala Space Observatory (OSO). It is a dual frequency microwave radiometer, measuring the sky brightness temperatures at the double-side bands centered at 21 GHz and 31.4 GHz respectively. Compared to the radiometer presently operating at the observatory, the new instrument is more compact and transportable. It will be used for comparisons at the Onsala site, especially studying the effect of narrower antenna beams. It will also be operated at other sites, e.g. in the Swedish GPS-network SWEPOS. Each channel uses two reference temperature black bodies (matched loads) for calibration: one "warm" - at regulated room temperature and one "hot" which is stabilized at 100 °C . The stability tests of the latter showed temperature bound within ±0.03° around 100 °C . The recent work on the microwave part and the data acquisition (DAQ) system is presented together with the solution for the positioning of the radiometer.

1 INTRODUCTION

In space geodetic techniques like VLBI[1] and GPS[2]-based surveys of the motions of the Earth's crust a major error source is the wet delay. The wet delay is the equivalent excess propagation path of the radio wave caused by the water vapour in the atmosphere. Information about the integrated water vapour content in the atmosphere can be derived from measurements of the sky brightness temperatures on and off the water vapour absorption line at 22.235 GHz . The idea is not new and it has been implemented in the already operating water vapour radiometer (WVR) - ASTRID. The virtues of the new WVR are the narrow antenna beams, the enhanced precision of the positioning, the data acquisition / control system (DAQ), and the compactness of the instrument. We present a summary of the work carried out on a new water vapour radiometer being developed at OSO. Section 2 presents the microwave system and the overall construction of the instrument. Section 3 discusses the solution of the DAQ system.

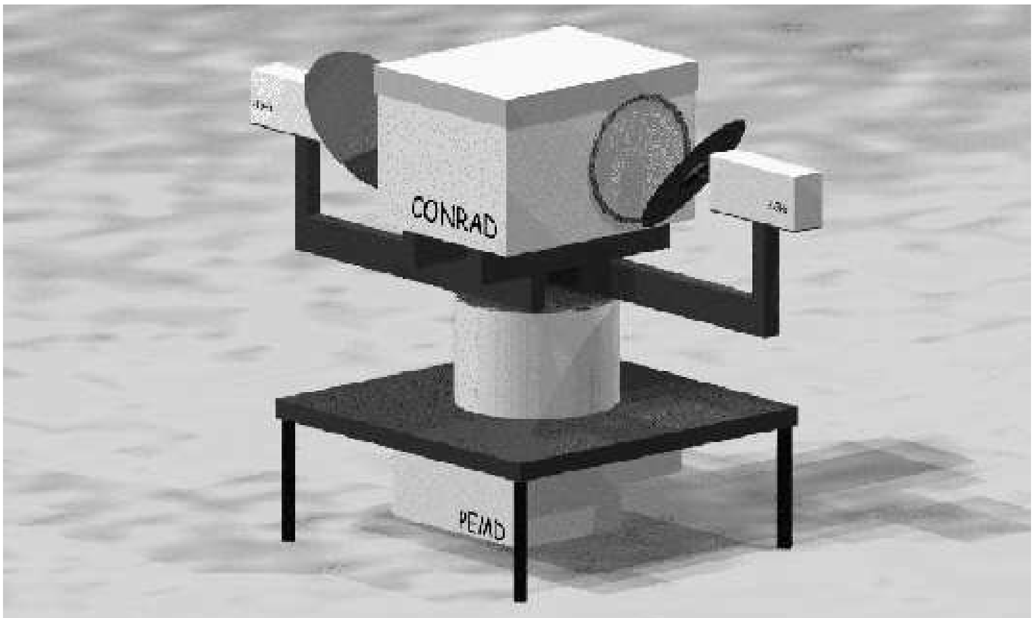

Figure 1. A view of the new WVR derived from the AutoCAD blueprints.

1. Very Long Baseline Interferometry.
2. Global Positioning System.

2 HARDWARE LAYOUT

The new WVR is equipped with two lens horn antennas - one for each of the two frequency bands. The two antennas are short but have rather large apertures. This suggested the usage of two pointing mirrors (one for each channel) for the different positions in the sky - a design which can be seen in Figure 1. The two mirrors (elevation) and the main axis (azimuth) are operated by stepping motors controlled by the positioning system run by sending commands from a personal computer (PC) to a microcontroller in the WVR.

The instrument is a dual frequency radiometer, with bands centered at 21 GHz and 31.4 GHz respectively. We will concentrate on the operation of only one channel, since the structure is identical for both channels (see Figure 2). The sky noise radiation enters the antenna towards the mixer through a mechanical and a ferrite switch. The voltage at the output of the detector is proportional to the total thermal noise power.

$$V_{sky} = G \cdot (T_{sky} + T_{sys}) \tag{1}$$

$$V_{warm} = G \cdot (T_{warm} + T_{sys}) \tag{2}$$

$$V_{hot} = G \cdot (T_{hot} + T_{sys}) \tag{3}$$

Ideally, the total system noise temperature should be split in two - the T_{sys} generated by all passive and active elements in the receiving system; and T_* which we assume to be the noise temperature of a black body - the sky, the “warm” or the “hot” load (depending on the configuration of the switches). In (1) the gain G and the temperature T_{sys} are not known, but can be calculated from the measured voltages V_{sky}, V_{hot}, V_{warm} and the controlled temperatures T_{hot}, T_{warm}. Different algorithms for retrieving the wet delay from the observed sky brightness temperatures are described in [1].

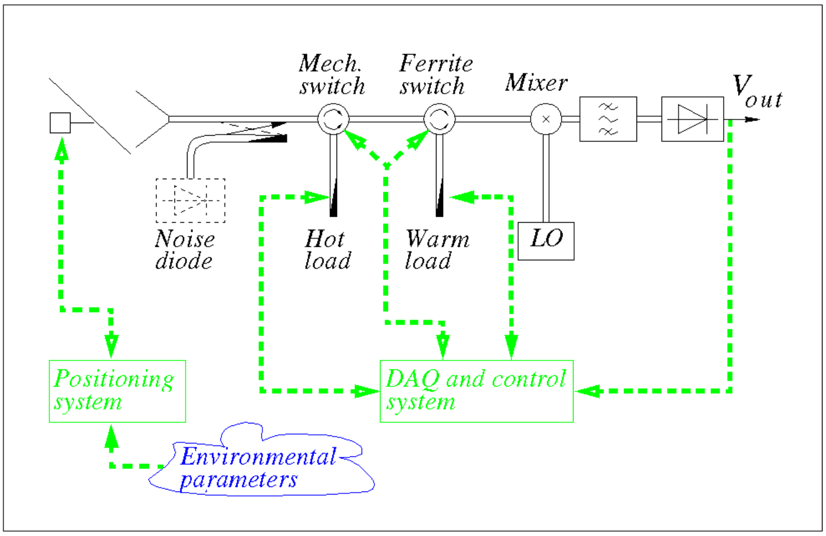

Figure 2. Structure of one microwave channel in the WVR.

The most important features of the microwave part and the data acquisition system are shown in Table 1.

Table 1. Features of the microwave and the data acquisition system.

Parameter	21 GHz channel	31.4 GHz channel
Lens horn antenna beam width	3°	2°
Physical temperature of the “hot” load (controlled)	100 °C	100 °C
Stability of the temperature of the “hot” load	±0.03°	±0.03°
Physical temperature of the “warm” load (measured)	~40 °C	~40 °C
Resolution of the ADC[a] measuring the output voltages, temperatures of the calibration loads.	16 bit	
Resolution of the DAC[b] controlling the temperature of the “hot” loads.	12 bit	
Communication with the PC	RS-232 (optical fibers) - up to 115200 bps	

a. Analog to Digital Converter.

b. Digital to Analog Converter.

3 DATA ACQUISITION SYSTEM

The Data Acquisition (DAQ) and control system is based on the commercially available FieldPoint / LabVIEW 5 products. They provide high quality measurements (eight 16 bit ADCs) and current generators (eight 12 bit DACs), along with discrete input and output modules for the waveguide switches. The communication between the PC running LabVIEW and the FieldPoint DAQ and control units is carried out over RS-232 serial interface. The LabVIEW programming environment provides a good basis for fast and easy development of user friendly software of satisfactory computational speed.

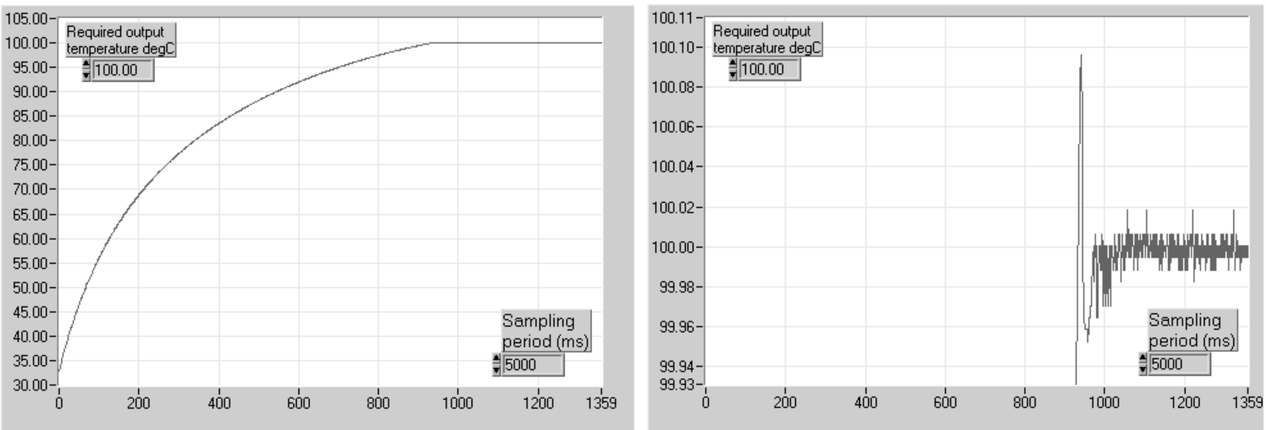

Figure 3. Convergence and stability of the temperature of the calibration “hot” load.

Software control is applied to the temperature of the calibration loads. Figure 3 shows the behaviour of the “hot” load for the 31.4 GHz band - the left figure presents the typical time needed for the “hot” load to heat up - approximately 5000 s or less than 1.5 hours[1]. The figure on the right is the same data zoomed

1. Since this is the slowest process taking place in the WVR, data acquired immediately after the start-up of the instrument should be discarded.

around 100 °C. The temperature is confined within ±0.03° which together with stable regime of the microwave hardware should ensure very slow changes in the gain from (1). A more detailed description of the choice of temperature control algorithm can be found in [2].

4 POSITIONING SYSTEM

Table 2. Features of the positioning system.

Parameter	**Azimuth value**	**Elevation value**
Stepping motors	5 phase	5 phase
Gears with low dead motion (less than 2 arcmin)	1:100	1:50
Holding torque	37 Nm	5.5 Nm
Step resolution achieved after the gear boxes (full step mode)	0.0072°	0.0144°
Angular velocity for the different axes	10 °/sec	> 10 °/sec
Resolution of the ADCs measuring the output voltages from the environment sensors (eventually air pressure, temperature, humidity)	16 bit	
Communication with the PC	RS-232 (optical fibers)	

5 PROSPECTIVES

The narrow beams of the lens horn antennas offer an instrumental basis for the evaluation and eventually improving the existing atmospheric delay models, especially for low elevations. The light weight and the size of the new WVR will allow studies to be carried out on various sites of interest.

REFERENCES

[1] Elgered, G., *"Tropospheric Radio-path Delay from Ground-based Microwave Radiometry",* repr. from chapter 5 in *Atmospheric Remote Sensing by Microwave Radiometry"*, edited by Janssen, M. A., John Wiley & Sons, 1993.

[2] Stoew, B., "*Microwave Radiometry: Data Acquisition and Software Based Temperature Stabilization",* M.Sc. thesis report, Chalmers University, Sweden, 1998.

[3] Beillon, A. and M. Lager, "*Construction of a Dual Frequency Dicke Switched Water Vapour Radiometer",* M.Sc. thesis report, Chalmers University, Sweden, 1992.