Microwave Observations of the Sun in Virac: An Experience of the Implementation

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Abstract: Microwave spectral polarimetric observations of the Sun still remain one of the significant issues of studies in solar physics and the space weather creation. Taking into account of the well-known mechanisms of microwave emissions in plasma these solar observations provide a unique opportunity for direct measurements of plasma parameters and magnetic fields in the upper chromosphere and lower corona. The analysis of spectra of the polarized solar emission allows to study the distribution of plasma parameters and inductions of coronal magnetic fields over a whole range of heights above the photosphere.

Nowadays Ventspils International Radio Astronomy Centre (VIRAC), Latvia has a possibility to perform regular routine multichannel spectral polarimetric observations of the Sun in the 2.1 – 7.4 cm wavelength range with RT-32 radio telescope in "single dish" regime. This paper reports on some physical, technical and methodical issues of the implementation of these observations. Feasible tasks and problems of solar physics, and studies of the space weather that could be addressed with the observations of interest are discussed as well.

keywords: solar physics, solar radio astronomy, space weather

1. Introduction

Ventspils International Radio Astronomy Centre (VIRAC) is one of the rapidly growing scientific institutions of modern Latvia. Today VIRAC is a member of the VLBI and LOFAR communities and is involved into a number of international astrophysical and space technologies projects. The implementation of microwave spectral polarimetric observations of the Sun and studies in solar physics and space weather origins based on these observations are a significant part of VIRAC astrophysical activity. In fact, VIRAC continues scientific directions and traditions of Baldone Radio Astrophysical Observatory, Latvia, one of leading solar physics centres of the former Soviet Union in 70-80's.

Microwave observations of the Sun in the wavelengths range of 1 -10 cm and the analysis of the polarized solar emission offer a unique opportunity for the direct measurements of plasma parameters and coronal magnetic fields in the upper chromosphere and the lower corona. Taking into account the well-known microwave emission mechanisms in a plasma and the fact that the emission at different wavelengths occurs at different heights depending on the current plasma kinetic temperatures and electron densities one could note an another advantage – the analysis of spectra of a microwave emission allows to obtain the distribution of plasma parameters and coronal magnetic field inductions over a range of heights above the photosphere.

VIRAC implemented its first successful microwave observations of the Sun in 2013 (Bezrukovs, 2013). Today, VIRAC has a possibility to perform regular routine observations of the Sun and obtain a microwave polarized emission of the whole solar disk at 2.1 – 7.4 cm wavelength range with multichannel spectral polarimeter installed onto VIRAC RT-32 radio telescope in a "single dish" regime (Bezrukovs, 2022). Implementing the whole circle of observations during years of maximal and minimal solar activity, VIRAC now has sufficient experience of technical and methodical issues of observations of the Sun, observational data processing, storage and distribution of the obtained data.

Even though the common ideology of microwave observations of the Sun was suggested in the 1960's (Kundu, 1965), routine multichannel microwave observations by "Sun-dedicated" radio telescopes were developed mostly over the past two decades. The chart of today's possibilities of regular microwave solar observations, i.e. daytime – wavelength range, for some known instruments is shown in the Fig.1. One can see that the amount of an eventual information about the microwave emission of the Sun is far from complete and sequential. Thus, VIRAC could take its defined part in

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common modern microwave observations of the Sun.

2. Hardware and Software

RT-32 radio telescope (Fig. 2,a) is the main VIRAC observational facility. The radio telescope is a fully steerable 32 meter diameter Cassegrain

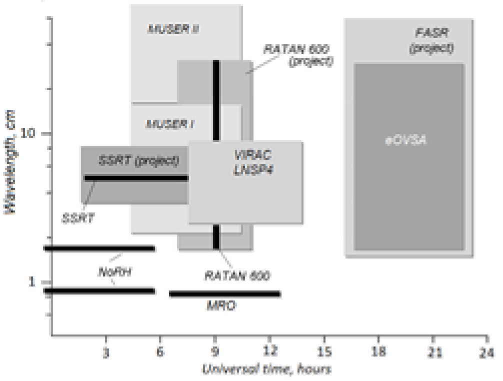

Fig.1. The daytime-wavelength chart of routine solar observations for some radio telescopes. Nobeyama Radio Heliograph (NoRH) is out of operation from March 2020 and it's data archives are available. VIRAC and Metsahovi Radio Observatory (MRO) are not “Sun dedicated instruments” but provide routine solar observations as well.

antenna. It's geographical position is 57°33'12" N and 21°51'17" E. The site has a low level of radio frequency interference (RFI) due to it's distance from industrial and communication facilities. Today the radio telescope is equipped with cryogenic S/X band receiver and L band receiver, the installation of the solar receiving equipment is in progress. Some parameters of the radio telescope are presented in Table 1.

Table 1. Parameters of VIRAC RT-32 radio telescope

Diameter of primary mirror	32 m
Precision of primary mirror surface (RMS)	~4 mm
Azimuth/Elevation tracking precision	10 arc sec
Azimuth movement limits	-328...+328 deg.
Elevation movement limits	2.5...90 deg.
Azimuth maximal speed	2.8 deg./sec.
Elevation maximal speed	2.25 deg./sec.

The new solar multichannel low noise spectral polarimeter (LNSP ver. 4, LNSP4) for the 2.1-7.4 cm wavelength range were developed on the base of the utilization of the previouse one. Now LNSP4 is expected to be installed permanently on RT-32 radio telescope after some reconstruction of the antenna central cabin and will be used as a main solar instrument.

The multichannel LNSP4 spectral polarimeter is expected to receive and detect a full flux power of the antenna beam for right and left circular polarizations in each frequency channel simultaneously. The LNSP wavelength range was divided to 12 frequency bands corresponding to the frequency grid of RATAN-600 solar spectral polarimeter. The newly developed LNSP4 has enhanced noise parameters, an extended dynamic range, an internal calibration noise generator, and the overall thermal stabilisation of the device. Some parameters of LNSP4 are presented in Table 2.

Table 2. Parameters of multichannel spectral polarimeter LNSP4

Frequency range	4.1 – 14.2 GHz (2.1-7.4 cm)
Number of channels	12
Channels bandwidth	250-800 MHz
Polarizations	RCP and LCP
S/N ratio (*T quietSun*/3□ *Tnoise*)	> 22-24 db
Dynamic range	>32 db
Sensitivity	>82 dbm
ADC	16 bit
Sampling rate	~ 10 samples/sec
RT-32 antenna HPBW	2.3-8.2 arc. min.
Internal noise generator	yes
Internal thermal stabilization	yes

In Fig. 2,b we show LNSP4 temporary installed onto RT-32 for test observations of the Sun. In these observations, the set of LNSP4, wideband feed Q-PAR 2-18 GHz and a Fresnel lens prototype for an optimal illumination of the feed were used.

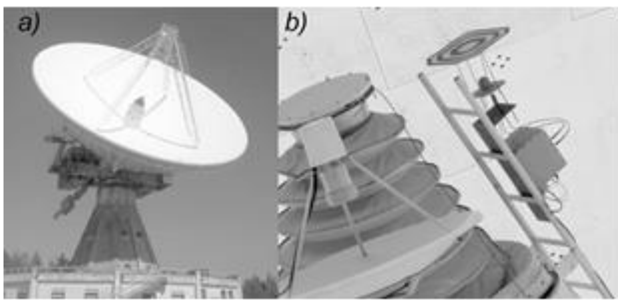

Fig.2. VIRAC RT-32 radio telescope (a). The temporary test installation of LNSP4+Q-Par feed 2-18 GHz+Fresnel lense prototype onto RT-32 (b)

The input of LNSP4 consists of wide-band low-noise amplifiers and controled attenuators for both polarizations, injectors of noise calibration signals and UHF commutator. The input signal band is divided to three subbands and processed by a set of band filters and quadratic detectors. Analog signals from detectors are measured by 16-bit ADC afrer muliplexing. All the units are controlled by a CPU, which gets commands from the control software via RS485 interface. The stabilization of the internal temperature of the device provides the stability of receiving parameters. A block diagram of LNSP4 is presented in Fig.3,a.

The system for routine solar observations consists of a set of hardware described above and the original software. It is integrated into RT-32 motion control system, a precise time (GPS/NTP server), data acqusition system, and observation control system ("Field system"). The whole set of hardware and software provides an observational session automatically.

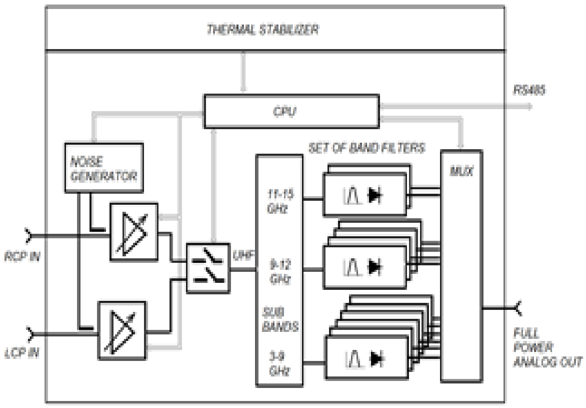

Fig. 3. The block diagram of LNSP4 spectral polarimeter

3. SOME METHODICAL ISSUES OF SOLAR OBSERVATIONS

The final result of a routine observational session is a set Stokes I and V spatial distributions ("maps") of antenna and brightness temperatures of the microwave polarized emission over the disk of the Sun for each frequency channel. Maps are presented in heliographic coordinates as FITS files. Primary observational data, all stages of its processing, and final resulting maps are stored in a multilevel archive. The structure of the archive is presented in Table 3.

The routine observational session itself includes some previous test observations of the Sun and clear sky and an automatic sequential scanning of the solar disk. As regular scanning with the spatial shift of the antenna beam relative to the centre of the Sun was performed for previous observations of the Sun. A spiral scanning around the centre of the solar disc were used (Mangum et al, 2007) also for last test observations. The observation control software prepares the antenna position table for the scanning taking into account the Earth rotation and the proper motion of the Sun on the epoch of an observation and provides the antenna movement in real time. Besides scanning, the observation control software is able to implement the tracking of separate active regions of the Sun taking into account the Earth rotation and the proper motion of active regions. The main stages of data processing are:

- selection of separate scans, filtering of RFI, relative calibration after the clear sky, and the centre of the Sun observations at the end of the each scan
- recalculations of the time-antenna position domain into heliographic coordinates at the epoch of the observations
- constructing of two-dimensional (2D) map and obtaining of missing pixels of the map by means of the bilinear interpolation or the interpolation with the modified MLM algorithm
- recalculations of two-dimensional maps to distributions of the absolute antenna temperature over the disk of the Sun based on observations of the microwave full flux emission the Sun with Nobeyama Radio Polarimeter (Tanaka et al, 1973; Bezrukovs el al, 2018).

The example of results of a sucessful test observational session with LNSP4 and VIRAC RT-32 for two of frequency channels is presented in Fig. 4. After a big radio telescope reconstruction since 2016-2017 a numerous test and routine observations were performed. Thus, a small but significant archive of the microwave observations of the quiet Sun was obtained.

Table 3. The structure of the multilevel data archive

Level 0	Raw observation profiles, sky test observations, Sun transit observations, antenna position data, antenna log files, calibration data
Level 1	Separate scans which are relatively calibrated after clear sky and centre of the solar disk observations, corrected and filtered. Recalculations of the time-antenna position domain into heliographic one.
Level 2	Set of 2D Stokes I and V distributions of relative antenna temperatures over the disk of the Sun for each frequency channel constructed by modified MLM interpolation (FITS files). Set of 2D Stokes I and V distributions of absolute antenna temperatures over the disk of the Sun for each frequency channel calculated after the microwave full flux emission (FITS files)

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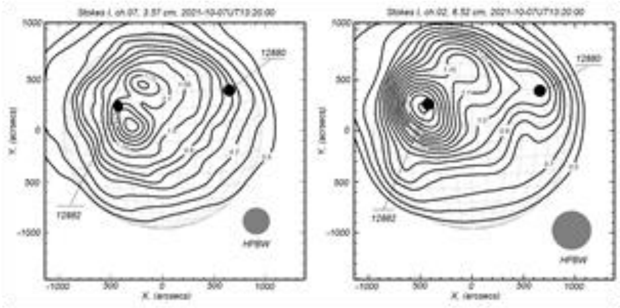

Fig.4. Distributions of Stokes I microwave emission over the disk of the Sun obtained with LNSP4 and VIRAC RT-32 radio telescope for 6.52 cm (channel 2) and 3.57 cm (channel 7). Brightness temperatures are referred to the quiet Sun one. The grid shows the optical disk of the Sun and positions of active regions at the epoch of the observation are shown also. HPBW of the antenna corresponding to the channel frequency is presented. The geometrical distortion of the map is caused by the spatial shift of the feed electrical axis from geometrical one and needs to be compensated.

4. POTENTIAL PROBLEMS THAT CAN BE ADDRESSED

Discussing feasible tasks and problems in solar physics, which could be addressed based on the microwave spectral polarimetric observations, one can point to the following ones:

1. **Coronal magnetography**. The problem includes the analysis of a spatial distribution of coronal magnetic field strengths and directions. Analysis of the microwave polarized emission of the solar coronal structures reveals coronal magnetic field strengths on the base of studies of the polarized free-free emission (Grebinskij et al, 1998; Gelfreikh, 2004,) and coronal magnetic field measurements through an inversion of polarizations due to quasi-transverse emission's propagation (Ryabov, 2004; Bezrukovs, 2011).

2. **Observations of microwave flux fluctuations in local sources**. The problem includes an analysis of the radio flux fluctuations resulting from the magnetic field emergence in active regions. Another point of the problem is an analysis of the microwave emission and its fluctuations of active regions associated with large, isolated sunspots in order to study the reduced plasma density and open magnetic fields in it and in its periphery (Ryabov, Shibasaki, 2016; Ryabov et al, 2021). Analysis of the radio flux fluctuations of active regions preceding solar flares in the frame of the problem is relevant also (Abramov-Maximov, Bakunina, 2020)

3. **Observations of the quiet Sun and coronal holes.** This common problem is rather wide and includes studies of the radio brightness of the quiet Sun and coronal holes (Borovik et al, 1990), and revealing the large-scale coronal loops as immediate relatives of distant active regions so as to reproduce sympathetic solar flares.

5. CONCLUSIONS

The VIRAC instrument has all of the possibilities to provide microwave spectral polarimetric observations of the Sun with multichannel spectral polarimeter at 2.1-7.4 cm wavelength ranges for numerous solar physics problems. During recent years a useful experience of solar observations, its technical, methodical and data processing issues has been gained. Some archive of 2D microwave emission maps of the active and quiet Sun has been established and it is accessible for the wide solar physics community.

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