# A new heliograph of the UTR-2 radio telescope: design and performance

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## Abstract

A new instrument dedicated to observations of the outer corona of the Sun has been put in operation since 2010. It is based on the antenna system of UTR-2 (Ukrainian T-shaped radio telescope, Mark 2) at the Braude's observatory of the Institute of Radio Astronomy. This radioheliograph is capable of producing two-dimensional brightness distribution pictures of the solar corona in the frequency range 8 - 33 MHz (height range of ≈ 0.7-2.3 solar radii above photosphere). It can be launched in different regimes (serial, parallel-serial and synthesis imaging principles). At present this is the only instrument of its kind in the world in the above-mentioned frequency range for regular observations of the Sun. Included in this report is a description of the instrument construction and its some features.

## 1. Introduction

The first configuration of heliograph was constructed on the basis of the radio telescope UTR-2 [1] else in the end of the seventies of XX century. A number of interesting radioastronomical observations of solar corona was carried out with help of this device. The results of the measurements (positions of stria-bursts forming chains in type IIIb bursts, parameters of diffusive stria-bursts or so-called echo-bursts in dependence of their source heliolongitudes in upper solar corona and others) were published in papers (see, for example, [2-4]). Unfortunately, the observations were realized only in some separated frequencies that do not allow one to perform full capabilities of UTR-2. In the last time the essential improvement of base blocks in the UTR-2 radio telescope (front-end [5] as well as back-end [6, 7]) was fulfilled. This enables us to make a qualitative leap ahead in radio astronomical studies at decameter wavelengths [8]. Together with them the heliograph has been modernized too. As a result the heliograph has made a great progress in development and now it is a unique low-frequency radio astronomical instrument with the extra newest capability and features represented in this report.

## 2. Antenna system

The main features of the heliograph are determined by the antenna characteristics of UTR-2. The broadband T-shaped radio telescope UTR-2 consists of two antenna arrays: "North-South" and "East-West". The larger arm "North-South" has 1800 meters along meridian and is divided into two separate arrays, each of which includes 720 wideband dipoles (six rows by 120 dipoles). The arm East-West spreads over 900 meters along parallel and includes six rows by 100 dipoles. All the elements in the arrays are oriented in the east-west direction and they receive linear polarization in that direction. The phasing discrete system of the radio telescope covers the sector $\pm 50^0$ in the right ascension plane and $\pm 80^0$ in the declination plane. In the antenna system the summation and phasing of signals are performed in such a way that each of the arrays (arms) is separated in four sections in front of the final phasing stage. The signal from each of the North-South array sections is divided into five outputs with the aid of hybrid branches. To get five pencil-shaped beams each output signal of East-West array sections is multiplied with the corresponding signal from one of five beam outputs of North-South array. At the zenith the telescope beam has the angular dimension about $25' \times 25'$ at 25 MHz, and the effective area of the UTR-2 antenna system is about 140000 m$^2$ [1].

## 3. General description of blocks

Therefore, the general construction of the heliograph includes the North-South and East-West antenna arrays. The additional (fast scanning) phase shift module is connected with outputs of East-West array sections. The switch boards of North-South and East-West arrays send a signal received from five equispaced pencil beams of these antennas one by one to the digital signal processor (DSP). The system of marker signals is integrated with the noise generator. Its aim is to form separating marks for each five-beam signals and beginning (ending) marks for each frame (consisting of $5 \times 8$ pixels) on heliograms. The signal value of frame beginning (ending) markers is higher than one of marks between five-beam signals due to the presence of 3 dB attenuator in the scheme. This allows us to avoid difficulties in the

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heliogram analysis after their records. The beam switch boards, the marker generator and the additional phase shift module are parts of the control system. The simplified version of the heliograph block diagram is shown in Fig. 1. Let us consider important features of this device in more details.

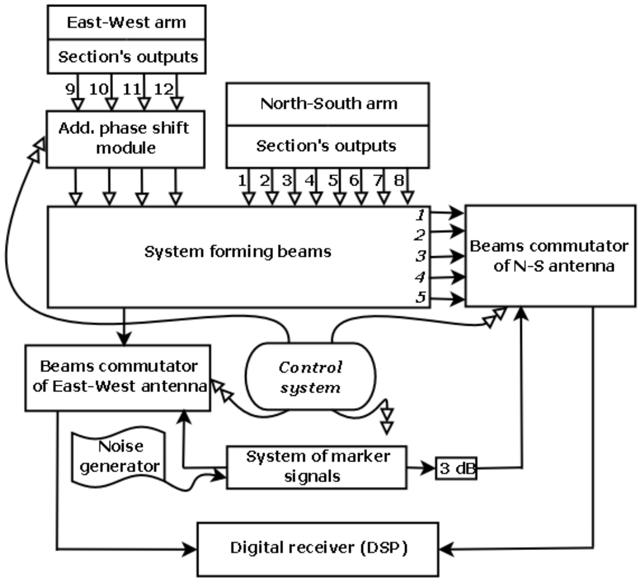


Figure 1: The general block diagram of the UTR-2 heliograph.

## 4. Potential of operating modes

To observe radio emission from both disturbed and "quiet" Sun by the regular registration facilities of the radio telescope, there exist a few operating modes to measure a two-dimensional brightness distribution in sky. At the present the heliograph basically uses a serial regime, where the output signals from five beams are registered one after the other, and the five beams of the antenna array pattern move on sky. This requires only one set of the recording equipment. In the parallel-series regime the signal of each beam is recorded by an independent set of the measured equipment. Totally this configuration uses five sets of the recording equipment. The last possible (parallel) mode allows ones to provide a synthesis imaging. In this regime the output signals received by all twelve sections are sent separately to twelve sets of the recording equipment (DSP).

## 5. Field of view

The heliograph image is obtained from signals received with help of the fast scanning of a sky origin by the pencil-shaped beam of the UTR-2 antenna pattern. In this case the beam takes five consecutive positions along $V$ and eight positions along $U$ coordinate in $UV$ -plane. In that way the complete picture of the field of view is a rectangular matrix consisting of 40 elements (pixels). The matrix image contains 5 rows and 8 columns spaced along declination and hour angle, respectively, at $25'$. The angular size of the heliograph image at 25 MHz is about $3.3^\circ \times 2.5^\circ$ along hour angle and declination at the zenith direction, respectively. The track system of the radio telescope UTR-2 realizes the Sun tracking in sky so that the center in the field of view coincides with the solar disk center.

## 6. Additional phase shift module

Although the UTR-2 radio telescope was assumed as a multitask instrument, its phasing system using electromagnetic relays does not permit ones to carry out the long-term observations in any fast beam scanning regime. To overcome this problem, this capability is realized on the base of the additional phasing system specially developed. Its phase shift module is located between the outputs of sections and respective inputs of the last phasing stage of East-West array. Consequently, the antenna section pattern envelopes all (five) scanning beam patterns. The additional phase shift module combines four identical components, each of which is a three-digit discrete-binary cable time-delay line. The line segments of coaxial cables are switched by diodes. The cable lines differ only in the values of time delays.

## 7. Switch boards

There are two types of switch boards used in the heliograph structure: the switch board of North-South antenna beams and the switch board for East-West array. The first from them connects sequentially the beam outputs of North-South antenna as well as the noise generator signal to one of two inputs of the recording device (DSP). The switch board of East-West array is designed to link the second input of the recording device either with the output of East-West antenna or with the noise generator. At the end of every cycle of the beam scanning the noise generator is connected with both recording equipment inputs instead of antenna arrays outputs.

## 8. Control system

The control system operates and monitors the fast scanning phase shift module, switch boards, the system of marker signals and attenuators to generate the corresponding sequences of control pulses. If the maximum frequency of clock pulses is 200 Hz, the scan rate is four cadres per sec. Each cadre consists of 48 elements in which 40 of them give an image, and others are marks. Due to a few operating regimes in the control system, it is possible to chose different times for forming heliograph shots. In particular, the shots can be obtained during 2 and 4 minutes in dependence of clock mode options.

## 9. Data processing

Nowadays the digital spectral processor (DSP) is used for heliograph (and not only) observations as a receiver-recorder device. This device contains two independent inputs. From these inputs any radio signal is digitized by one of two rapid analog-digital converters (ADC) and is cut on temporal intervals, where the signal can be accepted as a quasi-stationary pattern. Next, the FPGA matrix executes the fast Fourier transform (more precisely, cross-spectrum of two DSP-input signals) to find short-term spectrums for the received signal. The obtained spectrum data are saved in a hard disk of the personal computer in the form of a number matrix (frequency channels – time counts). The developed software provides a graphic interface output by means of which users can control the data recording options and watch the registered results in real time. The main characteristics of DSP is represented in Table 1.

In the present configuration the heliograph with the serial forming and registration of image elements one of two DSP inputs is connected with the outputs of North-South, and another receives radio signals from East-West array. It should be pointed out that the North-South array has five outputs corresponding to five beams, but the signals from these outputs are sent to the input of DSP one by one. A marker from the noise generator completes this scan cycle along five beams. It is switched to DSP instead of the array outputs. Such a marker forms a separation path on heliograms to reconstruct corona images.

Table 1: Parameters of the digital spectral processor.

| | |
|---|---|
| ADC sampling frequency | 66 MHz |
| Working frequency bandwidth | 8-33 MHz |
| Max. number of output frequency channels | 8192 |
| Frequency resolution | 4 kHz |
| Temporal resolution | from 0.2 msec up to 1 sec |
| Dynamic range | 117 dB |

## 10. Observations

By this equipment configuration the heliographic observations have been carried out in summer of 2010. The test observations included the nighttime investigations of radio emission from the cosmic sources 3C144 (Crab Nebula), 3C274 (Virgo A), 3C405 (Cygnus A), 3C461 (Cas A) and others. The listed sources are point sources for this heliograph. Moreover, they are enough strong in intensity at decameter wavelengths. This makes it possible to identify them clearly even in anyone frequency channel of their heliograms (i.e. without any frequency and time accumulation). However, for weaker sources (for example, 3C348) it is necessary to carry out the corresponding frequency (and/or time) average to detect their signals above noises.

One of the important goals in the heliograph study is to get two-dimensional brightness distributions of radio emission from outer corona for the quiet Sun. As is well known, the minimum of recent 11-year sunspot cycle fell at 2008. Years close to solar minima are very favorable for flux density measurements of radio emission from the quiet Sun corona. The monitoring of solar corona has been accomplished from 28 August to 3 September of 2010. The preliminary analysis of the heliograms has established clearly that the movement of solar corona (or brightest coronal regions) along heliograms, due to the diurnal motion of the Sun, is well identified. This demonstrates a good sensitivity of this instrument even for anyone frequency channel. In this connection it should be noticed that the radio astronomical observations at decameter frequency range are subject to a number of harmful factors interfering to get the robust data of measurements. Among them these are numerous artificial disturbances and natural interferences, propagation medium effects of radio waves distorting cosmic signals, very high temperature of galactic background and so on. The observation results will be described in more details elsewhere.

## 11. Conclusions

The distinctive features of the heliograph of decameter wavelengths on the base of the UTR-2 radio telescope show it as a unique radio astronomical instrument. It operates at the lowest frequencies (accessible to ground-based instruments) of radio emission observations among all radio heliographs in the world. Secondly, this heliograph is a broadband device covering the entire frequency range from 8 MHz up to 33 MHz. Thirdly, the instrument demonstrates unprecedented values in sensitivity, temporal and frequency resolution, dynamic range and spatial selection of signals at the given frequency range. No wonder, the heliograph enables us to fulfill fruitful observations not having analogs in the world. In particular, this device permits us to get two-dimensional images of the upper solar corona within 2-3 solar radii from center of the Sun almost without gaps in $(u, v)$- coverage during 1 sec. The sensitivity and the dynamic range of heliograph open wide perspectives to register the complex spatial evolution of low-contrast solar events (fine structure of radio bursts, filament structure of type II burst and others) simultaneously with very bright radio events (such as strong type III bursts or against background of type II and IV bursts).

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