The SSRT in the 23rd cycle of solar activity

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Abstract

We present a sketch of the project to upgrade the Siberian Solar Radio Telescope. We suggest expanding the spectral range of receiving frequencies from a single frequency (5.7 GHz) to five frequencies and to considerably improve the sensitivity of instrument.

Key words: Sun: Radio — Telescope

1. Introduction

There is no doubt that the 23rd cycle of solar activity will see no loss of interest in research on solar activity processes. This owes not only to increasingly stringent requirements imposed on prediction of geoeffective phenomena but also to a number of fundamental problems which still remain unsolved. It is general practice to interpret the physical phenomena on the Sun qualitatively. A changeover to a numerical simulation of them is of prime importance because the Sun's atmosphere is the natural laboratory which allows investigations to be made of plasma physics phenomena that occur on stars and are beyond the reach of laboratory studies. Solar activity processes encompass an extremely wide range of temporal and spatial scales. In these circumstances, the avenue of inquiry shifts from the study of separate phenomena and their characteristics to the study of the solar activity process as a single whole. The advancement of the solar astronomy is directed toward the creation of instrumental complexes that combine space-borne and ground-based observatories, including those in different countries. The development of computer networks and software opens the possibilities for remote on-line analyses of data.

An important complex of such a ground-based observatories could include the those of Japan, China and East Russia (Irkutsk) where almost simultaneous and impressively varied solar observations are being carried out. The unique feature of the Asian group is the availability of two large radioheliographs in Japan (Nobeyama) and Russia (Irkutsk) which are specifically designed to obtain solar radio images in the microwave range.

Radio observations make it possible to study the corona at the background of the solar disk and substantially enrich measurements in hard and soft X-ray emission. The variety of generation mechanisms for radio emission and their dependence on parameters of emitting electrons hampers the interpretation of observations in the absence of spectral data with high spatial resolution.

It is pertinent to note that the dynamic emission range is extremely wide: brightness temperatures from 10^4 K on the quiet Sun to 10^{10} K during powerful solar flares are observed. Because of this a further development of the experimental basis of radio astronomical observations is directed at the extension of both the dynamic and spectral ranges of observations.

Even a combined analysis of solar maps (Nobeyama radioheliograph — NRH, 17 GHz) and one-dimensional brightness distributions (SSRT, 5.7 GHz) provided qualitatively new results derived from investigating a number of events of solar activity cycle 22 (Altyntsev et al., 1998; Uralov et al., 1998). In the cycle 23 the SSRT started observations in the correlation mode, making it possible to obtain two-dimensional solar maps at 5.7 GHz frequency at 3—5-min intervals with a spatial resolution as high as $22''$ (Uralov et al., 1998). The NRH carries out observations at 17 GHz and 34 GHz simultaneously. Nevertheless, the set of frequencies calls for further extension.

2. The method of formation of radio images at the SSRT

The SSRT is a crossed interferometer with antenna arrays in the E-W and N-S directions, 622 m in length, each of which consists of 128 antennas (Smolkov et al.,1986). Since the orientation of the interference maximum depends on the frequency, it is possible to obtain 1d—images of the solar disk by readjusting the receiving system's frequency. Consequently, by performing this discrete readjustment with sufficient speed (or by processing the received signals simultaneously from a large number of frequency channels), we obtain a sequence of scans, one—dimensional solar images. The method of frequency scanning permits readings to be taken rapidly in a single direction. This is used directly in the SSRT observations of fast active processes with a time resolution of up to 14 ms.

To obtain two-dimensional radio images, we use a combined operation of the linear arrays as a crossed correlation interferometer. Its directional pattern consists of a set of interference maxima, pencil-shaped beams, which are oriented in a regular manner in the hemisphere. Beams oriented within field of view of single antenna are involved in the formation of solar radio images. As the Sun passes through the fan of the beams (consecutive interference maxima) due to rotation of the Earth, it is scanned in one direction. In combination with a grid of counts obtained through a frequency scanning in other direction, this ensures a two-dimensional mapping of the Sun.

3. Technical implementation

The solution of the problem of expanding the spectrum of receiving frequencies is based on changing the narrow-band antenna feed used at the radio telescope now, for composite multi-wavelength feeds on running wave resonators to receive the signal, and for the installation of amplifier-converter SHF modules. The SHF modules separate a discrete set of frequencies in the 2 - 9.4 GHz band and convert them to the frequency of the SSRT wave-guide line of 5.7 GHz (Fig. 1) for following consecutive recording.

At the focus of the parabolic mirror of 2.5 m in diameter are mounted three integrated feeds of V.N. Dikiy's design (Dikiy et al., 1982) inserted into each other. The phase centers of these feeds are brought into coincidence. The left- and right- handed circularly polarized components of the emission, received by antenna, arrive from each feed at the polarization modulators (V) and then at SHF amplifiers with 15 dB gain and the input noise temperature of 50 - 60 K. The signal from the 5.7 GHz amplifier are promptly fed to multiplexer. The signals from the amplifiers (2 - 4 GHz, and 7.4 - 9.4 GHz) are fed to the mixers, the other inputs of which are connected to the multiplexers which switch on local oscillators with 1.8 GHz and 3.6 GHz frequencies, respectively. The frequency of the local oscillator is formed by the voltage with 100 MHz frequency which is fed to all mirrors, with a subsequent frequency multiplication by factor of 9 - to simplify filtering of the combination frequencies of the multiplier - and then with a frequency multiplication by factors of 2 and 4. Since the output frequency of the mixer is 5.7 GHz (SSRT central frequency), the following input frequencies are sampled: 2.1, 3.9, 7.5 and 9.3 GHz. The signals from the multiplexers are fed to the wave-guide. Before entering the wave-guides, the signal propagates in the strip- micro-line where it is possible to install diode modulators to be used in the SSRT diagnostic complex (checking the accuracy of antenna pointing, measuring the amplitude and phase distributions for the radio telescope, etc.).

The five sub-ranges are recorded sequentially. The time needed to scan the entire range is 20 ms, 4 ms for each sub-range. This, in turn, requires switching the polarization modulators with a period of 4 ms and recording signals in each half-period with the accumulation time of 2 ms. A reduction in sensitivity that is caused by sequential measurements is compensated for by averaging. The time of averaging (up to 160 ms) is limited by the smearing of the interference pattern leading to a decrease in spatial resolution at the highest frequency (9.3 GHz).

Also, we plan to improve substantially the radio heliograph sensitivity using the correlation of the envelopes of signals. In the two-dimensional mode the noise is added by signals formed by the SSRT linear interferometers, i.e. signals from the Sun received by the knife-edge beam. All signals, except for those received from the area at the intersection of the beams, are incoherent. The essence of the proposed method for improving the sensitivity is as follows. The 2T-bridge of signals from the linear interferometers (E-W and N-S) has two outputs: one for the sum of in-phase signals, and the other for the sum of anti-phase signals. According to calculations and results of a simulation by means of wave-guide units, most of non-correlated noise is compensated. In our scheme signals after a conversion with a common local oscillator (G) and amplification are recorded from two acousto-optical receivers (AOR) with a common laser (LG) on CCD-arrays. Processing is carried out using the correlation of the envelopes of received signals and most of non-correlated noise must be compensated. A requirement for a substantial improvement in sensitivity is the low noise level of the input line, i.e. low losses from the feeds to the low-noise amplifiers in the SHF module, as well as the noise of these amplifiers, because this noise has no correlated envelope.

Furthermore, the project makes for the possibility of observing fast processes with a time resolution of 20 millisecond and high one-dimensional angular resolution, concurrent with a mapping by recording signals from the SSRT linear E-W and N-S interferometers.

One difficulty encountered in implementing the project is the requirement for a phase stability of voltage transmission with 100 MHz frequency to each antenna. Let us consider some ways of overcoming it:

1. By transmitting the signal via a RF cable. A total length of cables in this case will be 43 km, which is

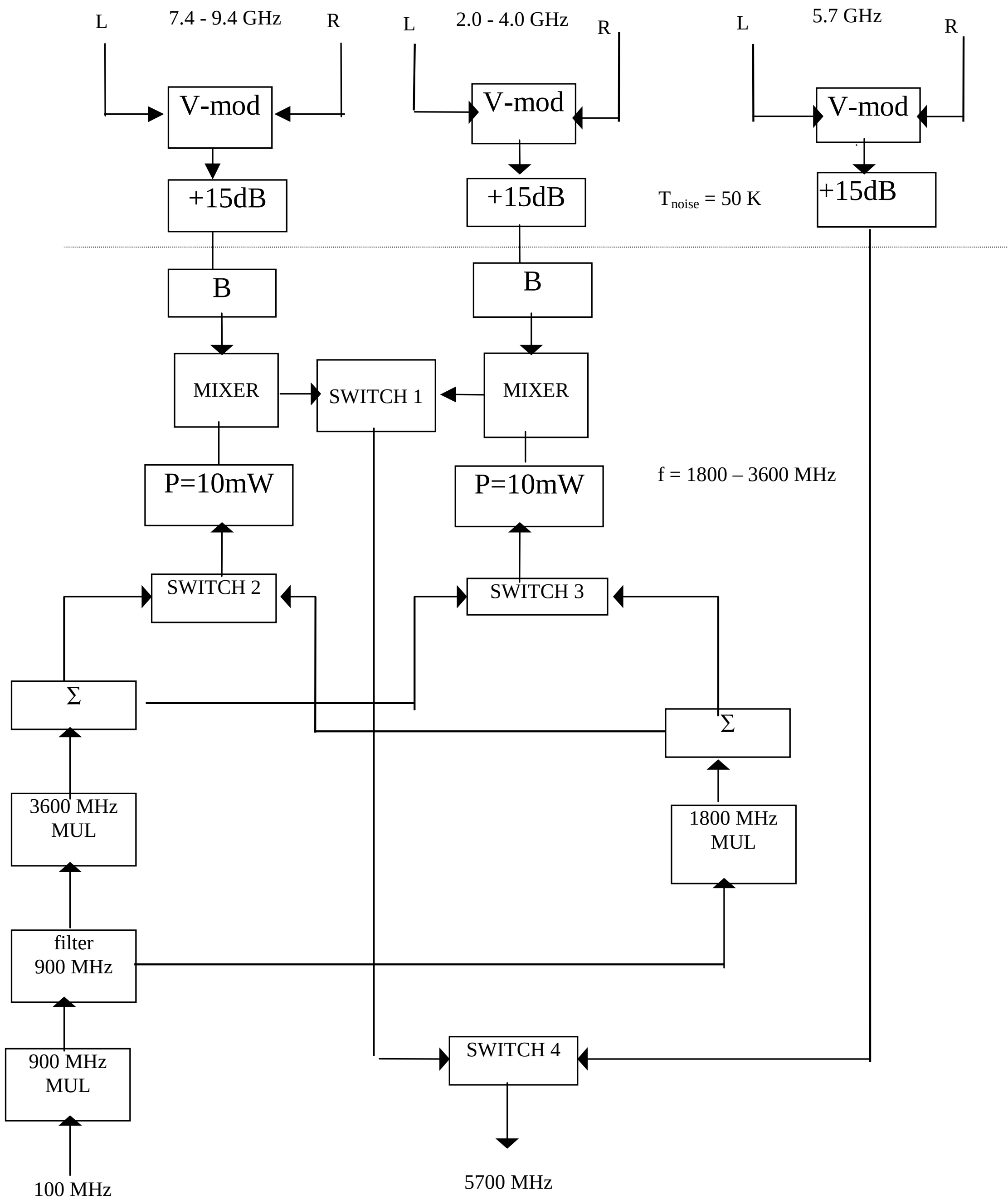

Fig. 1.. Scheme of the radio-frequency side

rather expensive. The signal power loss difference between central and distant antennas reaches 30 dB whose compensation is a separate problem. Besides, the equalization of electrical lengths of the cables presents a technically rather complicated problem.

2. By transmitting the signal by means of fiber-optic lines. But this avenue of attack on the problem appears to be at a deadlock because these lines are currently too costly, and converters (256 sets) are also expensive.
3. By transmitting the signal using the light ray from semiconductor lasers whose radiation is modulated by the voltage with 100 MHz frequency. In this method, at each antenna are installed high-frequency diodes, and the electrical lengths are equalized through a longitudinal displacement of them.

4. Alternative variants of SSRT modernization

The proposed project for an extension of the SSRT capabilities is chosen out of several variants:

4.1. Improvement of the radio telescope's spatial resolution

To achieve this goal, it is necessary to increase the baselines of the interferometers. Two approaches are possible: either by increasing the number of the radio telescope's antennas keeping them equidistant, or by transforming the SSRT antenna arrays into compound-interferometers. In this case, the number of additional antennas will be small; however, these dishes must be large in size in order to retain the radio telescope's sensitivity.

This variant does not seem promising for two reasons. In the first place, an improvement of spatial resolution to better than $10''$ will not add substantial new information at our frequencies. Investigations have shown that the sources (including burst-producing sources) with the such angular sizes occur rarely. This is accounted for by a substantial influence of coronal turbulence upon the scattering of radio emission. Secondly, any serious design and development efforts, the manufacture of antennas with support/rotation devices, and a large amount of construction and installation work are currently extremely expensive and not realistic.

4.2. Synthesis of images using correlators

Conversion of signals to low intermediate frequencies (50—70 MHz) and transmission of them to the telescope center where using one-bit correlators it is possible to synthesize the solar radio image in parallel, as done at Nobeyama (Japan) and at the VLA (USA). In this case the number of antennas can be reduced by a factor of 2 or 3, i.e. they can be chosen by the criterion of maximum filling of the spatial frequency spectrum. Increasing the receiver's bandwidth can compensate the decrease in sensitivity, caused by a reduction in the overall effective area. Our estimate of the cost of this variant comes to exceed several times the value of the proposed project because of a great number of correlators and a significant length of signal transmission lines.

5. Conclusion

Nowadays there are no radioheliographs which operate on five sub-ranges with a nearly five-fold frequency span ratio and which observe the Sun during almost the entire daytime. The proposed solution will make it possible - based on the modernization of an operating radio telescope - to create a fundamentally new instrument, a bandpass-response radio heliograph with direct formation of the image (unlike aperture synthesis systems used in most current radio telescopes). The implementation of this program on the basis of the SSRT will result in the creation of an instrument meeting state-of-the-art requirements to become a base instrument for cooperative research.

The special advantage of the proposed reconstruction is an almost total utilization of the existing SSRT equipment: antennas, the composite wave guide line with amplifiers, bridges and phase shifters, and receiving systems.

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