RADAR INVESTIGATIONS OF THE SOLAR SYSTEM OBJECTS AT EXTREMELY LOW FREQUENCIES

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The first discussion on the use of a radar to study the Solar System has been introduced by F. J. Keer [14], and F. G. Bass and S. Ya. Braude [3]. The research of the Sun with a radar technique became to be of particularly king interest. The next step in this trend was made in Massachusetts Institute of Technology by El Campo array [1, 2, 4], [10]–[13]. The first results with reflected signal from the Sun were obtained on El Campo array

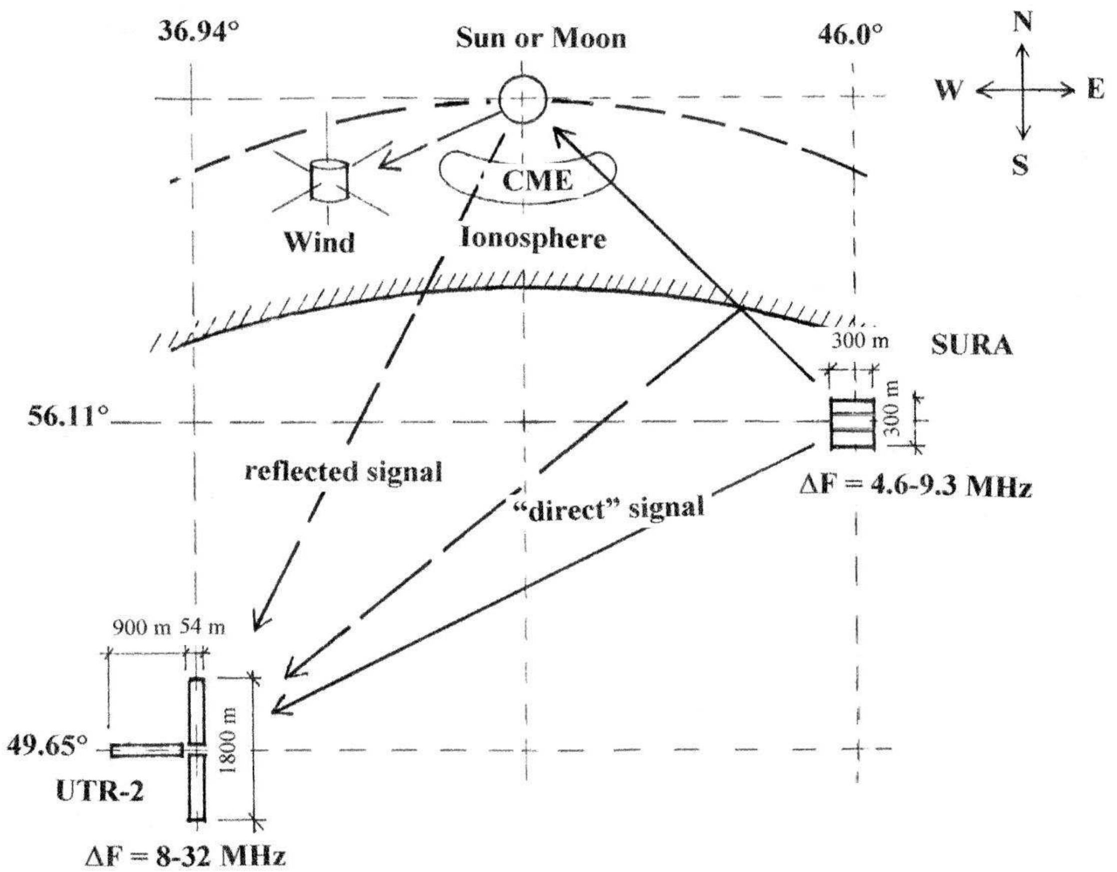

Figure 1: The general scheme of the using of the bistatic Radar SURA–UTR-2 in the radiolocation experiments

Table 1: El Campo – SURA – UTR-2 Radar System Comparison

N	Parameter	Dimension	**El Campo**	**SURA**	**UTR-2**
1	Transmitted power	P_{Tr}, [kW]	500	750	–
2	Transmitted antenna gain (Sun direction)	G_{Tr}, [dB] k	32 1585	18 63.1	–
3	Receiving antenna area (Sun direction)	A_R, [$10^3 m^2$]	35.688	–	45.6 [1] 112 [2]
4	Transmitter frequency	F_T, [MHz]	38.25	8.913; 8.953	–
5	Ionospheric losses	L, [dB]	~ 2	~ 4	~ 4
6	The background temperature	T_B, [K°]	$\sim 2.5\times10^3$	–	$\sim 5\times10^5$
7	Temperature of the quite solar corona	T_S, [K°]	1×10^6	–	1×10^5
8	Antennas Temperature	T_A, [K°]	$\sim 1.55\times10^5$	–	$\sim 4.78\times10^5$ [2]
9	Scattering cross-section (typical value)	$\sigma/\pi\ R^2_\Theta$, [m^2]	3.0	–	Unknown (estimation > 3)
10	Doppler resolution	Δ F, [kHz]	10	–	< 1
11	Total bandwidth	Δ BW, [kHz]	200	–	120
12	Radiometric gain	G_R	38	–	Unknown (same James)
13	Beam width (Sun direction)	NS°× EW°	0.592×6	22.8×6.3[3] 6.3×6.3[4]	1.15×31.69[2] 1.15×1.03[5]
14	Latitude	Lat, [deg]	29.189 N	56.116 N	49.654 N
15	Longitude	Long, [deg]	96.2 W	46.0 E	36.942 E
16	Signal to Noise ratio	S/N, [dB]	10	–	> -10 (estimation)

[1] – for East-West array;
[2] – for North-South array;
[3] – for one SURA section;
[4] – for three SURA sections;
[5] – for pencil beam lobe of the UTR-2;
$R_\Theta = 7\times10^8$ [m] – the radius of solar photosphere.

in 1961. This program was prolonged up to 1969 and the sequence of the successful events were analyzed and interpret by I. M. Gordon and N. N. Gerasimova [5]–[8].

One of the reasons that stimulated our interest to follow research is the incoming satellites population in the Earth surrounding and the necessity to predict the Cosmic Weather, disturbances of nearest interplanetary plasma and Geomagnetic disturbances [9, 15]. In this paper we show only preliminary results on Sun and Moon radiolocation, which were obtained in the framework of the contracts N F61708–97–W0230 and N F61775–98–WE088 between the EOARD and Institute of Radio Astronomy of the NASU in 1996–1997.

The main task of this project is the preparation and realization of radar investigations of the Sun with the goal to detect the coronal mass ejections (CMEs). CMEs are ones of the most important and interesting phenomena in the solar physics and solar terrestrial relations. According to the preliminary estimations a high frequency radar can be one of the most effective means for detection of these phenomena. This technique is the most effective if it has to be applied for a bistatic configuration, for example, when the Russian SURA high frequency transmitter and the Ukrainian UTR-2 receiving antenna array (Fig. 1) are used.

The preliminary estimates of the radiolocation potential (see in Table 1) show a good possibility of registration of reflected signal from the Sun at 9 MHz. The comparison between El Campo and SURA–UTR-2 radars was made for the quite Sun conditions at the time on June 22. In our estimations we used the parameters similar to Jesse James parameters, but we didn't know the cross section and radiometric gain values. We supposed these values are to be similar to James parameters.

Our estimations show (see rows 16 in the table) that an expecting signal to noise ratio is more than –10 dB. But we know that our detection limit in similar radio astronomy observations (for example in pulsars observations) reaches the level of –15 dB. Unfortunately, we were not to be sured that the real Sun reflected signal was obtained. The best spectra where the presence of the reflected signal is the most probable were obtained on July 21, 1996. During the other séances of the Sun radiolocation a reliable registration of the reflected signal was absent.

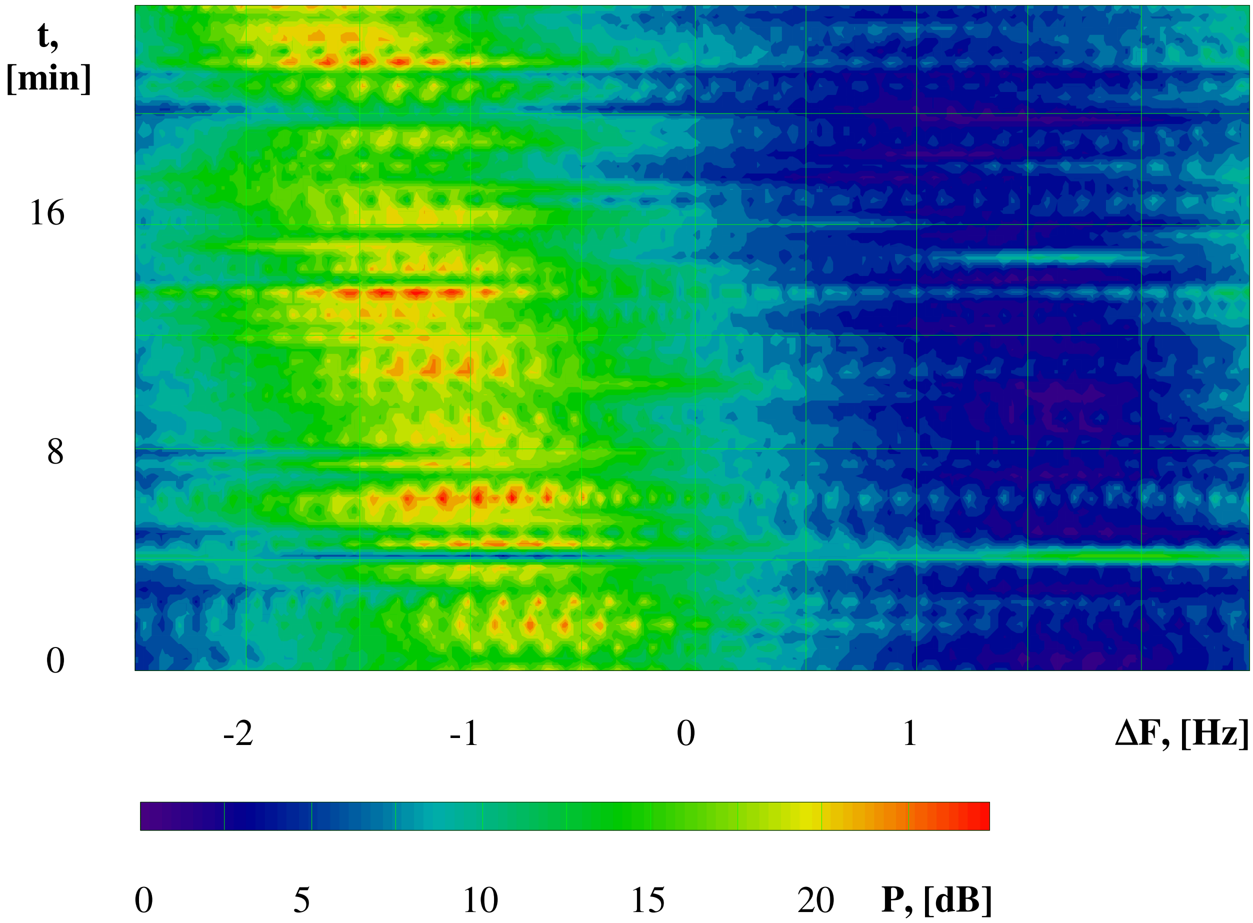

Figure 2: Dynamic Cross Correlation Function between the SURA "direct" and Moon reflected signals (The Moon radiolocation session from July 14, 1996).
Parameters of the SURA transmitter signal:
central frequency of the transmitter $F_C = 8.920$ MHz $\rightarrow$ $\Delta F = 0$;
total transmitter power $P_{S3} = 210$ kW (only third SURA section);
modulation by "ON-OFF" code with period $T = 5$ sec; "ON" duration $\Delta\tau = 1.2$ sec

The absence of the reflected signal in our data can be explained if we suppose that the cross section is to be significantly less than $3\pi R_{\Theta}^2$ (where R_{Θ} is the radius of the solar photosphere), or radiometric gain is to be considerably less than 38 dB, or the result losses are to be more than 8 dB at 9 MHz. The little scale plasma turbulence in the top of solar corona at 9 MHz may be considered as a physical evidence for the first hypothesis (cross section is significantly less than $3\pi R_{\Theta}^2$). From another side the radiometric gain decreases when the reflected signal looks like a noise signal and its scale of Doppler shifts is very broad. It means that the signal is reflected from solar plasma inhomogeneities, which have different light velocities. Our result can be explained more easy by ionosphere losses, refraction and scattering in interplanetary plasma. These questions require an additional examination because we have no possibility to compare our calibration data for the Moon (Fig. 2) and the same Jesse James data (if Jesse James used such a calibration).

During performance of the Sun radiolocation, the solar activity was daily to be patroled. These observations allowed to reveal a correlation between parameters of the reflected signal and different types of solar activity. Unfortunately, registration of the signal reflected from the Sun is impossible when the solar activity is highly strong at 9 MHz.

CONCLUSIONS

Special facilities and detection procedures were developed and introduced in regular operation at the SURA–UTR-2 radio telescopes for the Sun and the Moon radar experiments. These facilities allowed us to reduce interference effects and to reach the sensitivity maximum. Methods to check the ionospheric conditions with the Sun and Moon radar experiments simultaneously were developed. The signal reflected from the Moon was detected with a high reliability.

The Sun radar experiments require to follow its at the transmitter frequency up to 20–25 MHz. A new transmitter should be situated near the working radio telescopes. The CMEs detection at extremely low frequencies can be successful only in the periods of a low Sun activity. The probability of CMEs existence is higher in the period of a high Sun activity, but in this period there are another problems for the study at low frequency range due to increasing the critical frequencies in ionosphere. The very interesting phenomenon was detected on September 17, 1997, when the Sun burst type III with 1000 solar flux units density at 12 MHz has been cut off after 10 MHz. This phenomenon supports our point of view. So, the requirements for detection of CMEs and appearing CMEs are in contradiction to the results at the lowest frequencies.

The necessary attribute in the CMEs locations is the monitoring of solar activity. The main task of this monitoring is to put conditions when the ionosphere is transparent and the Earth-Sun information channel exists at low frequencies. The combinations of active and passive methods of CMEs detection will be very useful in future investigations.

We plan to compare results of ground-based solar patrols and satellite observations with the results of our analysis. Undoubtedly, the solar radar experiments must be continued to develop this technique.

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