The study of solar flares with microwave sub-second pulses at 5.7 and 17 GHz

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Abstract

Flares with fine-structured features in their time profiles are of a special interest as sub-second time structures are attributed to processes of primary energy release. Using two-frequency microwave data recorded by the SSRT (5.7 GHz) and the Nobeyama Radioheliograph (17 GHz) together with X-ray data, we have comprehensively studied two flares with sub-second emission pulses (September 6, 1992 and November 2, 1992) and have started with two more (September 7, 1992 and March 3, 1994). In all four flares the impulsive sources found at 5.7 and 17 GHz coincided with the main sources of the burst continuum observed at these frequencies.

Key words: Sun: flares — Sun: magnetic fields — Sun: particle emission — Sun: radio radiation — Sun: X-rays, gamma rays

1. Introduction

Flares with fine-structured features in their time profiles are of a special interest as sub-second time structures are attributed to processes of primary energy release. Having two-frequency microwave data recorded by the Siberian Solar Radio Telescope (SSRT, 5.7 GHz) and the Nobeyama Radioheliograph (NRH, 17 GHz) together with X−ray data, we have a chance to study emission mechanisms and physical conditions favorable for generation of sub-second pulses (SSP) and, probably, to find out what does proceed in sites of energy release.

Since 1992, more than thirty fine-structured bursts were recorded by the SSRT. At least 20 events with SSP were detected by the NRH. However, we have found only a few of them, in which fine time structures were recorded by both radio telescopes.

2. September 6, 1992 flare

The ordinary slender impulsive flare of September 6, 1992 (NOAA 7270) observed on the solar disk was described in detail in some publications based on data obtained by the *Yohkoh* X−ray telescopes, optical telescopes (NAO, Mitaka), NRH (Hanaoka, 1993; Yaji et al., 1994; Kurokawa et al., 1994), and SSRT (Altyntsev et al., 1998a).

Two pulses with durations ≤ 100 ms were recorded at the SSRT during this microwave burst. The flaring region was observed simultaneously in two orders of interference. The coincidence of the positions of the SSP source in the different interference orders and the agreement between their time profiles confirm their solar origin. The durations of both pulses were near or below the temporal resolution of 56 ms. Fast NRH records of this event are not available.

Positions of the SSP sources coincided with the sources of the unpolarized continuum. The X-ray source S1 (Yaji et al., 1994) corresponded to the loop-top SXR-emitting region. The loop was oriented from south-east to north-west, and its footpoints were visible as areas of intensive brightness in hard X−ray images.

The electron density and the magnetic field in the flaring region were estimated with the help of multi-spectral data. The sources of the continuum and the SSP at 5.7 GHz were located in the vicinity of a compact region with a plasma density in excess of 10^{11} cm^{-3} and the magnetic field of about 100 G. Those conditions suggest that the SSP were generated by harmonic plasma emission in sites of high electron densities.

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3. September 7, 1992 flare

The event of September 7, 1992 (NOAA 7276) was a slender limb flare (Altyntsev et al., 1998b). The background burst was rather weak, and the maximal flux was observed at 9.4 GHz. No significant polarization was recorded at all frequencies. Flux of the impulsive emission was well above the background one. There were pulses of up to 4 s.f.u. in the interval of 10 s at 17 GHz. FWHM duration of each pulse did not exceed 200 ms.

SSRT record is available in this case. Regrettably, the timing accuracy of the SSRT was insufficient to study sub-second delays with other data. Nevertheless, there was the obvious similarity of the temporal structure (see Altyntsev et al., 1998b).

There was a point-like impulsive source with a size of less than the beam of the NRH. The burst had a response at 05:10 UT in GOES−7 record of 5−min averaging (4.0×10^{-7} counts/sec at 0.5–4 A and 3.1×10^{-6} counts/sec at 1–8 A). From those values it follows that the plasma temperature was 1.2×10^7 K and the emission measure was $n_e^2 V \approx 3.4 \times 10^{48}$ cm^{-3}.

Analysis made by means of Ramaty's code (Ramaty, 1969) showed that the background burst could be emitted by electrons in the energy range of 0.05–3 MeV: $N(\mathcal{E}) = 3.5 \times 10^{27} \mathcal{E}^{-2.2}$ $[MeV^{-1}]$, assuming the angle between the magnetic field (700 G) and the line of sight $\simeq 85°$, and the density of the background plasma of $< 7 \times 10^{10}$ cm^{-3}. The upper limit of the plasma density is determined by Razin effect.

Outstanding is the correspondence of the total flux time profiles at both frequencies and hard X−ray ones. The one-to-one correlation was observed with time profiles of X−rays within the range of 25–50 keV. The similarity of the microwave profiles with the 50–100 keV ones was not so marked.

The microwave pulses at 17 GHz were observed with a delay of ~ 4 ms with respect to 25–50 keV HXR ones. Assuming that the growth time of plasma emission was an order of the collision time of background plasma $1.65 \times 10^{-2} T^{3/2} n_e^{-1}$, we get an estimate of the delay $\simeq 0.7$ ms for $T_e = 1.2 \times 10^7$ K (with $n_e = 10^{12}$ cm^{-3} for the second harmonic) which is of the order of the observed delay. The estimate of T_e was obtained from the ratio of fluxes recorded in GOES channels. The assumed density agrees with the estimate of the soft X−ray emission measure. From $n_e^2 V > 3.4 \times 10^{48}$ cm^{-3} follows the source size of $V^{\frac{1}{3}} \simeq 1.5 \times 10^3$ km.

4. November 2, 1992 flare

The limb flare of November 2, 1992 started at 02:30 UT (NOAA 7321) was a prominent powerful LDE which was studied in detail by Altyntsev et al. (1995, 1998b, 1998c) using spatially-resolved observations at the NRH and the SSRT. The structure of microwave sources varied considerably during the initial steady exponential growth of both T_B and flux. Sub-second features were recorded at different frequencies in various time intervals. At 17 GHz, SSP occurred during the initial exponential growth (around 02:44:50 and 02:45:10 UT). Their source was located 15×10^3 km above the limb, and its size was close to the NRH beam (7 thousand km ×10 thousand km). Close to the peak of the burst (02:54 UT), a new source appeared which contributed considerably to the total flux at 5.7 GHz, but was not seen at 17 GHz. The SSP at 5.7 GHz were emitted by that source. There was no response at 17 GHz to these pulses. The turnover frequency of the microwave spectrum of the flare was well above 10 GHz at this time. The sources of the SSP at both frequencies coincided with the brightest points of the background burst.

The compact source of the SSP at 17 GHz was due to gyrosynchrotron emission of electrons with the energy of 1–2 MeV (see Altyntsev et al., 1998c for details). Our estimate of the magnetic field in the flaring region is about 300 G. It had the size of 2×10^3 km and was located at a height of 15×10^3 km. The SSP observed at 5.7 GHz near the impulsive peak were generated in an optically thin source due to plasma emission. From the study of similar pulses observed during the flare of September 6, 1992 occurred on the solar disk, it had been shown that the source was projected onto the top of a dense loop. In the limb flare of November 2, 1992, the dense SXR loop-top was located inside the optically thick dome-like source, and the sub-second impulsive source was much higher. The estimate of plasma density in the main dome-like source was $\sim 2.1 \times 10^{10}$ cm^{-3}. If the plasma density in the surroundings of the impulsive source was of the same order, then, to realize the density of $\geq 10^{11}$ cm^{-3}, the background plasma in the impulsive source must be compressed a few times. Such a compression is reasonable for a reconnection site, where the energy release occurred.

5. March 3, 1994 flare

The event of March 3, 1994 (NOAA 7682) was an ordinary slender flare of C6.2/SF class and was observed on the disk. The spatial structure did not pass through appreciable changes. The source of SSP coincided with the main

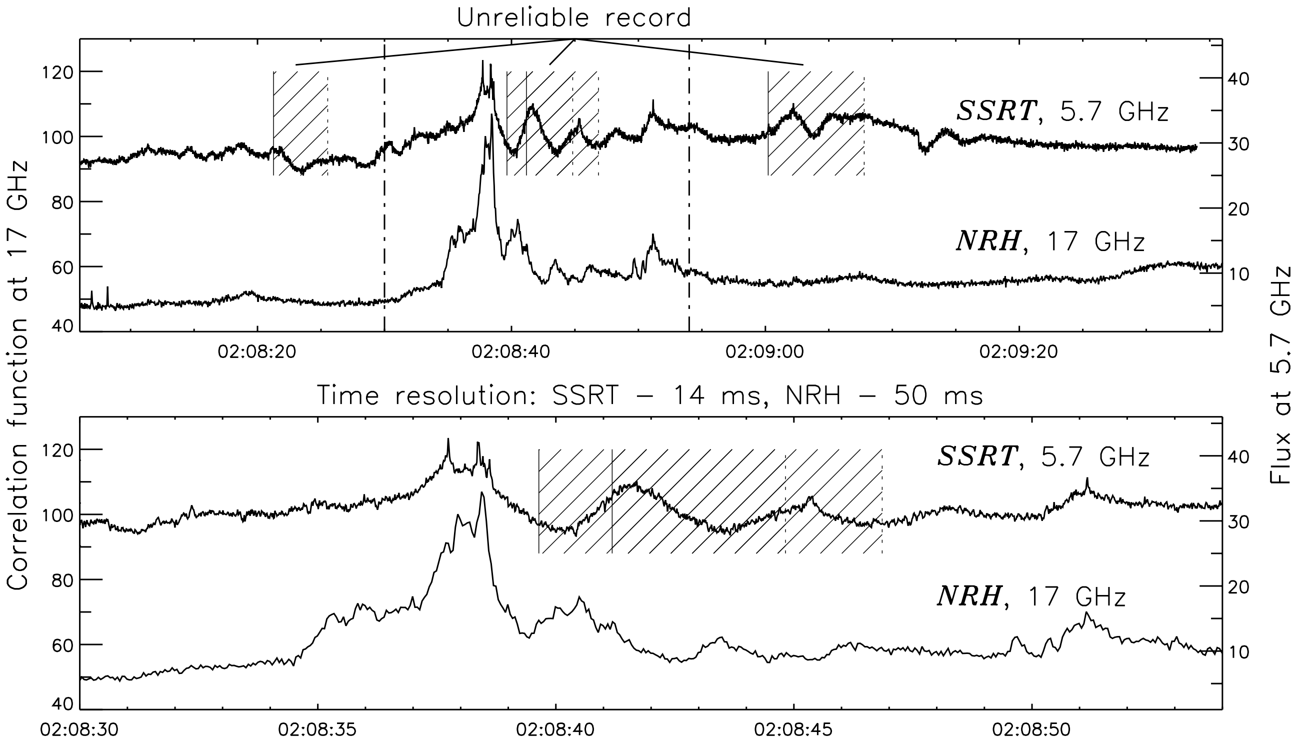

Fig. 1.. The flare of March 3, 1994. Microwave time profiles

source of the burst continuum and seems to be located in a loop's footpoint. Remarkable is the correspondence of the details of the time profiles at both frequencies (Fig. 1).

Magnitude of the SSP was 4 s.f.u. at 5.7 GHz and 0.8 s.f.u. at 17 GHz. Close correspondence of the SSP at 02:08:38.4 UT can be seen at such different frequencies. This event was recorded with 14 ms resolution at the SSRT. Another sub-second pulse occurred 20 s later was longer at 17 GHz than at 5.7 GHz.

There were two polarized sources separated in $E-W$ direction by $52''$. The brightness center was situated slightly southwards from the western source of positive polarization ($8''$). Degree of polarization did not exceed 6 % for the western source and -13 % for the eastern one. SSP occurred in the brightness center whose localization was not changed during the flare.

The study of nature of those SSP is incomplete because polarimeters of Nobeyama Radio Observatory did not operate in March 1994, and the accuracy of timing at the SSRT was insufficient to measure the delays between signals.

6. Conclusion

The study of flares using complex data of different emission ranges allows to estimate plasma parameters in the vicinity of SSP sources. In the investigated cases, the SSP were emitted from regions with a moderate magnetic field. The sources were found to be compact.

The emission mechanisms appeared to be various at 17 GHz. The basic way of appearance of SSP at 5.7 GHz is plasma emission.

The considered events suggest that sub-second structures can be recorded at both frequencies if they are generated in footpoints rather than in loop-top sources.

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