Solar Physics with Radio Observations, Proceedings of Nobeyama Symposium 1998, NRO Report 479

Microwave observations of sub-second pulses with spatial resolution

Alexandr ALTYNTSEV[1],* *E-mail(FI): altyntsev@iszf.irk.ru*
Hiroshi NAKAJIMA[2], Toshiaki TAKANO[3], Victor GRECHNEV[1] and Sergey KONOVALOV[1]

[1] *Institute of Solar-Terrestrial Physics, Lermontov St. 126, Irkutsk, Russia 664033*
[2] *Nobeyama Radio Observatory, NAOJ, Minamimaki, Minamisaku, Nagano 384-1305, Japan,*
[3] *Department of Natural Science, Chiba University, Chiba, Japan*

Abstract

A few tens of sub-second pulses (SSP) have been recorded since 1992 by the SSRT (5.7 GHz) and the Nobeyama Radioheliograph (17 GHz). At both frequencies, SSP occurred at any phase of flare bursts.

Temporal and spatial characteristics of SSP observed at both frequencies were studied.

For three 17 GHz events, BATSE/CGRO data of 64 ms resolution are available. There are several sub-second structures in HXR data which are highly correlated with microwave pulses.

Emission mechanisms of SSP are discussed and plasma parameters in the sources are estimated.

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

1. Introduction

Interferometric observations with millisecond resolution during the whole daytime have been available at 5.7 and 17 GHz since 1992 (Altyntsev et al., 1994; Takano et al., 1994). One of the advantages of interferometric observations is that they ensure the solar origin of the observed events. Some tens of sub-second pulses (SSP) well above the noise level were recorded. At both frequencies, SSP occurred at any phase of background flare bursts. A study of those events has a great importance for the problems of fragmented energy release and electron acceleration in solar flares. SSP are also convenient for studying the emitting plasma as the emission pulses are short, and SSP sources are supposed to be very compact.

The nature of the SSP emission has not yet been established, and none of the current theoretical models have been generally accepted. Until now, only a few spatially resolved SSP observations have been reported.

2. Duration

Observations at the SSRT show that the SSP appear at 5.7 GHz in ~ 15 % of flares. Most of them had a duration in the range of 20–200 ms (Altyntsev et al., 1996a). The minimal recorded duration of 20 ms is certainly a lower limit due to the comparable time constant of the receiver. Appropriate simulations showed that the minimal observed pulse duration corresponded to the real one of ≤ 5 ms. The flux pulses were distributed after their duration into two clusters with a mean duration of 50 ms (26 pulses) and 150 ms (15 pulses), respectively. The r.m.s. width is about 25 ms for each group.

About 20 powerful sub-second pulses were recorded starting from the beginning of observations at the Nobeyama Radioheliograph (NRH) with the temporal resolution of 50 ms. For the analysis, the intervals of 3–5 min were selected which showed prominent fine structures in routine profiles of the correlation amplitude sampled by 1 s. The distribution has maximum at about 0.5 sec, but it is possible that we lost a number of SSP shorter than this value.

---

[*] A. T. Altyntsev stayed at Nobeyama Radio Observatory as Foreign Research Fellow of National Astronomical Observatory.

3. Source sizes

The apparent sizes of the SSP sources at 5.7 GHz reach some tens of arc seconds and increase towards the solar limb. The center-to-limb dependence of the source size can be explained by scattering of the emission due to density fluctuations along the ray path in the solar corona (Altyntsev et al., 1996b). This dependence for a point source was calculated by Bastian (1994) basing on the analysis of the spectrum of density fluctuation in the outer corona and extrapolation of the results towards the lower coronal layers. It follows from this that the Bastian's curve must be the lower boundary for the observed sizes of all bursts' sources (see Altyntsev et al., 1996b). The sizes of the SSP sources at 17 GHz are close to the NRH beam width (about $10''$) in all cases. So the real sizes of the sources are believed not to exceed a few arc seconds at both frequencies.

4. Location of SSP sources

Positions of SSP sources coincide in most cases with brightness centers of the sources of underlying continuum except for a few events, which showed a displacement of $\leq 10''$. As we saw, sizes of background bursts' sources at 5.7 GHz were larger than the SSP ones. At 17 GHz, background bursts' sources were mainly small. In the event of September 7, 1992 (01:55 UT) with the relatively large size of the background burst, the SSP were located close to the brightness center of the polarized emission which was spaced apart from the intensity one. For some events, soft X-ray images are also available. Positions of the SSP sources observed on the solar disk were close to the footpoints of the SXR-loops (Takano et al., 1994).

Heights of SSP sources can be estimated when they were observed in limb events. In the powerful flare of November 2, 1992, the SSP were observed at both frequencies (Altyntsev et al., 1995, 1998a). The SSP occurred at 17 GHz in the beginning of the rise of flux, and the source had a height of 15×10^3 km. The source of the SSP emission at 5.7 GHz was found to be close to the maximum of the background burst, and it was located at a height of $\simeq 30 \times 10^3$ km, well above the SXR-emitting loop with high plasma density and temperature and relatively low magnetic field.

In the event of September 7, 1992 (05:55 UT), the SSP occurred simultaneously at both frequencies (Fig. 1). The source recorded at 17 GHz was located close to the limb. The 1-D image of the SSP recorded at 5.7 GHz coincided with the SSP source observed at 17 GHz. Note that the low-frequency source was considerably wider due to the anomalous high scattering of the emission in the lower corona. The degree of the angular broadening due to the scattering depends on frequency as $1/f^2$.

5. Correlation of SSP with hard X-ray pulses

For three events recorded at 17 GHz, BATSE/CGRO data of 64 ms resolution are available. We used data accumulated in two channels oriented towards the Sun, which were kindly prepared by R. Schwartz. There are several sub-second structures in HXR data which are highly correlated with microwave pulses, regarding the relative timing as well as the pulse duration. Peak brightness temperatures and degree of polarization of the background bursts are given in Table 1.

To correlate the BATSE and the NRH subsecond time structures, the trends of the background emission were subtracted. The background trends were found as a set of minima of the signal taken within the interval of 2 s moving along the record. Trends were smoothed with the same width. When the fine time structures were extracted, we cross-correlated the profile of the 25–50 keV BATSE channel with X-ray time profiles of other energy channels and with the profiles of the microwave emission. The values of the delay $(t_i - t_{25})$ and the cross-correlation coefficient (CCC) are given in Table 1 for the cases $CCC > 0.3$. Uncertainties of the cross-correlation measurements were estimated by means of Monte Carlo simulations. This approach was described and verified for BATSE signals by Aschwanden and Schwartz (1995).

The most remarkable is the event of September 7, 1992 (05:09 UT) when the source was located on the solar limb, and the corresponding SSP at 5.7 GHz were also recorded. There is a high one-to-one correlation between HXR and microwave spike emission at both frequencies, and the values of the relative delay are small. The delay between 17 GHz and 25–50 keV HXR emission was considerably less than the delays of about 0.3 s which were reported for radio emission at 1.3 GHz by Aschwanden et al. (1993).

Table 1. The analyzed events.

Date Time	August 12, 1992 02:32:19 UT	September 7, 1992 01:55:02 UT	September 7, 1992 05:09:22 UT
Flare	1N	SF	SF
GOES, W/m^2			
$1-8$ A	4.3×10^{-6}	2.1×10^{-6}	3.1×10^{-6}
$0.5-4$ A	7.1×10^{-7}	2.4×10^{-7}	4.0×10^{-7}
AR	NOAA 7248	NOAA 7270	NOAA 7276
Location	W51/S13	W43/S09	E86/N15
		Microwave burst	
T_B, K	3.3×10^5 $(1.2 \times 10^6)^*$	7.4×10^5 (2.2×10^5)	2.5×10^5 (1.2×10^6)
Polarization	-18 %	14 %	-7 %
		Delay, ms/CCC	
17 GHz	$+59.5 \pm 6.0/0.35$	$+27.5 \pm 4.2/0.85$	$+3.8 \pm 1.9/0.82$
$50-100$ keV	$-15.1 \pm 5.0/0.85$	$-9.4 \pm 7.5/0.88$	$-20.9 \pm 2.3/0.95$
$100-300$ keV	....	....	$-47.8 \pm 5.0/0.75$

* Brightness temperatures of the SSP pulses are given in brackets.

6. On the origin of SSP

The time relations between hard X-rays and radio waves in the frequency range of 0.1-1.5 GHz have been interpreted by Aschwanden et al. (1993) in the framework of coherent plasma emission. HXR pulses preceded the radio bursts at 1.24 GHz by 0.3 s. This delay has been mainly explained by essentially different energy of radio ($\leq$ 5 keV) and hard X-ray ($\approx$ 80 keV) emitting electrons.

Estimates of brightness temperature at 5.7 GHz are rather high in some cases, and a coherent emission mechanism is favoured. The comparison of radio flux and *Yohkoh*/HXR data on the September 6, 1992 flare suggests that the energy of SSP emitting electrons was $<$ 40 keV (Altyntsev et al., 1998b). Together with the estimate of the magnetic field of $\sim$ 100 G, it supports plasma emission as the origin of SSP at 5.7 GHz.

The apparent brightness temperature of pulses at 17 GHz did not exceed 1.2×10^6 K. As for incoherent mechanisms, such brightness temperatures can be explained in terms of gyrosynchrotron emission, but they are too high for free-free emission.

Gyrosynchrotron mechanism was suggested for interpretation of 17 GHz SSP emission seen in the rising phase of the November 2 flare (Altyntsev et al., 1998a). In this powerful limb flare, there was a sequence of pulses with a conspicuous response at 9.4 and 5.7 GHz. The spectral maximum of the SSP in that event was lower than 10 GHz, and the source was located well above the chromosphere (about 15 thousand km). Polarization of the background burst and the pulses was low. Regrettably, fast HXR data were not available in this case.

Unlike the previous event, the response to the 17 GHz SSP at other frequencies was weak in the September 7, 1992 (05:09 UT) flare. ¿From the one-to-one similarity of shapes of microwave pulses and hard X–rays and small delays between them it follows that the energy of electrons emitting 17 GHz and 25–50 keV HXR emission was close. According to the estimates obtained by Aschwanden and Schwartz (1995) for BATSE measurements, electrons that produce HXR emission of $25-50$ keV have an average kinetic energy of $\mathcal{E} > 2E \approx 80$ keV. To get relatively high flux at 17 GHz due to gyrosynchrotron emission of electrons with the energy of $\sim$ 100 keV, we must assume too high magnetic field in the source which contradicts low degree of polarization of the SSP. So we believe that for a part of the SSP observed at 17 GHz, the harmonic plasma emission mechanism is a plausible consideration.

This conclusion does not contradict data on remarkable event described by Kaufmann et al. (1985). The burst of May 21, 1984 exhibited very fast time structures at 30 GHz and 90 GHz which well correlated with X-ray emission in the range of 24–219 keV. There was no delay down to the temporal resolution of the X-ray measurements (128 ms).

¿From estimates of the energy of emitting electrons for different frequencies, we can speculate that this energy increases with frequency of SSP. For plasma emission, increase of the frequency corresponds to growth of background plasma density in SSP source. It can be naturally explained by dependence of Coulomb collision mean free path on energy. To emit at higher frequencies, non-thermal electrons have to penetrate denser plasma layers.

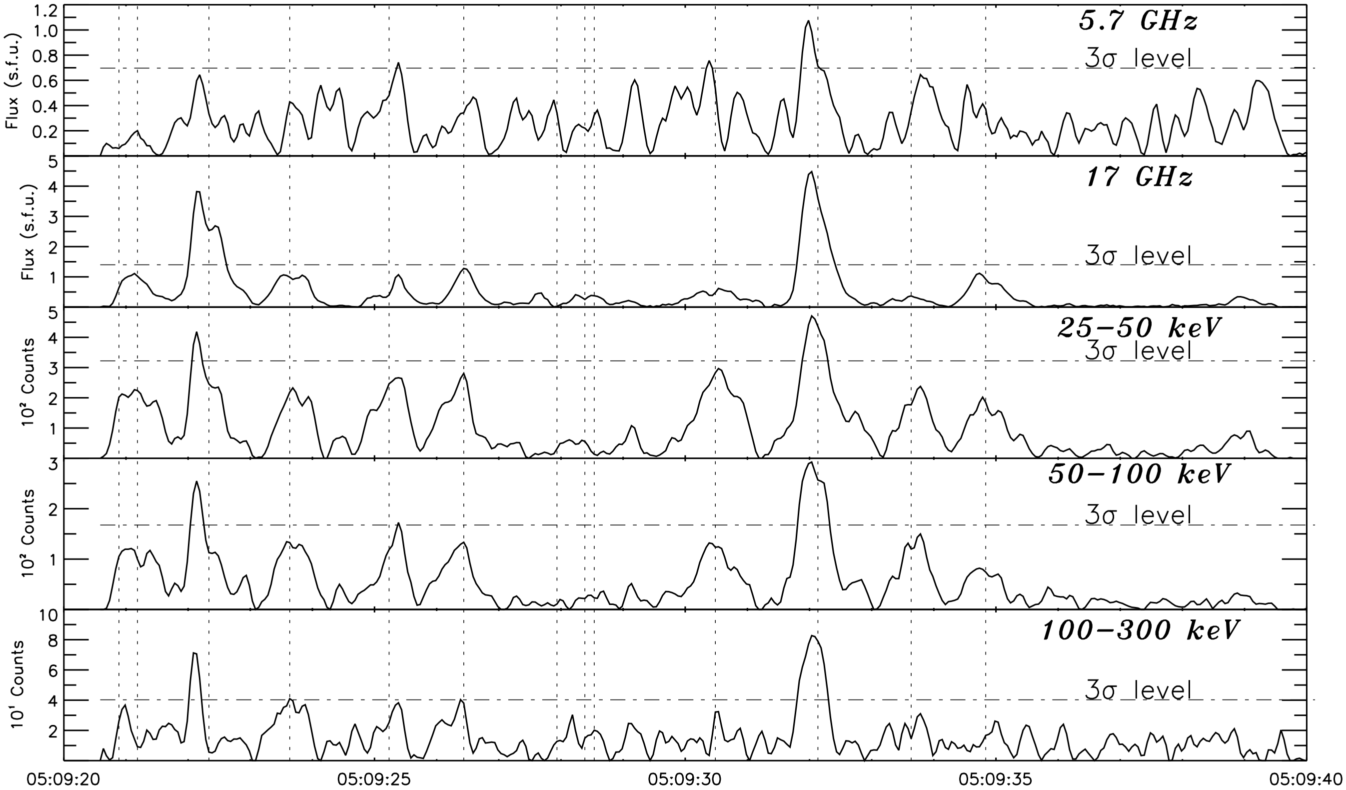

Fig. 1.. Multi-spectral time profiles of the September 7, 1992 event. All the records were smoothed over 0.15 s.

This work was supported by the Russian projects of *RFFI* No. 96-02-16648, No. 97-02-16906 and *Astronomia.* V. Grechnev and A. Altyntsev appreciate the hospitality and the help of Nobeyama Solar Group during their work in Nobeyama Radio Observatory.

References

Altyntsev A. T., Grechnev V. V., Kachev L. E., Lesovoi S. V., Mansyrev M. I., et al. 1994, A&A 287, 256

Altyntsev A. T., Grechnev V. V., Zubkova G. V., Kardapolova N. N., Lesovoi S. V., et al. 1995, A&A 303, 249

Altyntsev A. T., Dutov A. A., Grechnev V. V., Konovalov S. K., Krissinel B. B., et al. 1996a, Solar Phys. 168, 145

Altyntsev A. T., Grechnev V. V., Konovalov S. K., Lesovoi S. V., Lisysian E. G., et al. 1996b, ApJ 469, 976

Altyntsev A. T., Grechnev V. V., Nakajima H., Fujiki K., Nishio M., and Prosovetsky D. V. 1998a A&A, submitted.

Altyntsev A. T., Grechnev V. V., Hanaoka Y. 1998b, Solar Phys. 178, 137

Aschwanden M. J., Benz A. O., Schwartz R. A. 1993, ApJ 417, 790

Aschwanden M. J., Schwartz R. A. 1995, ApJ 455, 699

Bastian T. S. 1994, ApJ 426, 774

Kaufmann P., Correa E., Costa J. E. R., Zodi Vaz A. M., Dennis B. R. 1985, Nature 313, 380

Takano T., et al. 1994, Proc. of Eight International Symposium on Solar Terrestrial Physics, June 5–10, 1994, Sendai, Japan, p. 44