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SOLAR SIMPLE BURSTS OBSERVED WITH HIGH SPECTRAL RESOLUTION IN THE 18–23 GHz RANGE

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ABSTRACT

For the first time, solar bursts in the frequency range of (18–23) GHz have been observed with high-time (0.6–1.2 s) and high-frequency resolution (1 GHz), by using the Itapetinga 13.7 m diameter antenna. Here, we investigate the microwave type "simple low level (<10 SFU) bursts" associated with the impulsive phase of solar flares. Observed properties of these simple bursts are: rise time $t_r \sim 3$ s, decay time $t_d \sim 5$ s and spectral index ranging between −1 and −4. These bursts were found to be associated with SF or SN flares as seen in Hα. The above properties suggest that they are likely to be a microwave counterpart of elementary flare bursts. In the majority of the cases the spectral evolution is *soft-hard-soft.* This suggests a nonthermal gyrosynchrotron mechanism for generating these elementary flare bursts. Estimated parameters of these simple burst sources are height ($h \sim 2400$ km), electron density ($N_\epsilon < 8.8 \times 10^9$ cm^{-3}), and magnetic field ($\boldsymbol{B} \sim 300$ G).

Subject headings: radiation mechanisms: nonthermal — Sun: radio radiation

1. INTRODUCTION

During the typical impulsive phase of solar flares of duration of order 10–100 s, energy of order 10^{26}–10^{32} ergs is liberated, and some of this energy goes to in X-rays. Association of the hard X-rays with type III bursts of the duration of order 1 s leads Van Beek, De Feiter, & De Jager (1974) to suggest the concept of the elementary flare burst (EFB), that is, energy of the flare is liberated in each EFB, and the flare is composed of many such EFBs. Typical duration of EFBs is ~5–25 s. This suggestion was further confirmed by De Jager & De Jonge (1978). Recently De Jager & Sakai (1991) have suggested explosive coalescence mechanism for generation of such EFBs.

Kaufmann et al. (1985) reported the counterpart of this EFB in a millimeter wavelength at 22 GHz and named them "simple bursts." Detailed investigations of temporal and polarization characteristics of these bursts lead them to suggest that probably these "simple bursts" are a response to single injection of the energetic electron beam. However, these observations were at a single frequency, and the knowledge of the spectra of these bursts was badly needed to take these investigations further.

Realizing the importance of the high spectral resolution microwave observations, a frequency agile interferometer in the frequency range of 1–18 GHz has been put into regular operation by Hurford and his colleagues (Hurford, Read, & Zirin 1986). Sawant & Cecatto (1990) have extended this frequency range up to 18–23 GHz. Briefly, instrumentation of this high sensitivity and high time resolution millimeter radiometer is described below. With this radiometer we have observed so far five low-level simple bursts in the frequency range of 18–23 GHz. We describe the temporal properties of these bursts and for the first time investigate the microwave spectral evolution, soft-hard-soft, and suggest that simple bursts are generated by nonthermal gyrosynchrotron processes by the electrons accelerated during the rise time of the simple bursts. We also determine source parameters of the simple bursts.

2. INSTRUMENTATION

A microwave (18–23 GHz) variable frequency radiometer has been in regular operation since 1988 on a time-sharing basis using a 13.7 m diameter antenna (Sawant & Cecatto 1990; Sawant et al. 1992). The antenna is calibrated at the time of solar observations by using standard radio sources such as Jupiter, Virgo A, or Orion. Also, calibration of the antenna temperature is done by using a reference absorber. This eliminates the effects of atmospheric absorption to the first-order effects (Ulich & Haas 1976). Absolute receiver temperature of the system is obtained by using a reference temperature ~300 K and liquid nitrogen temperature ~77 K. Values obtained for 18–23 GHz ranged between 1724 and 1082 K, respectively. The sensitivity of the radiometer varies between 0.03 and 0.05 sfu depending upon the temperature of the active region in comparison to the temperature of the quiet sun expressed in percentage P. The above values of the sensitivities are for P equal to 20%–120%, respectively.

3. OBSERVATIONS

Solar observations in the frequency range of 18–23 GHz were carried out from 1989 June until 1991 November during six different periods with a total of about 535 useful hours of observations. During these periods were reported about 45 groups of impulsive and 21 gradual microwave bursts. An interesting case of impulsive simple burst of the duration of order of 1 s superposed on the gradual burst has been reported here (Fig. 1). The time resolution was 1.2 s in the periods 1989 Jun 14–Jul 1 and 1990 May 3–7, and 0.6 s in the others. The durations of the observed bursts ranged from ~3 s and 5 minutes with flux values ranging from 2 to 200 sfu.

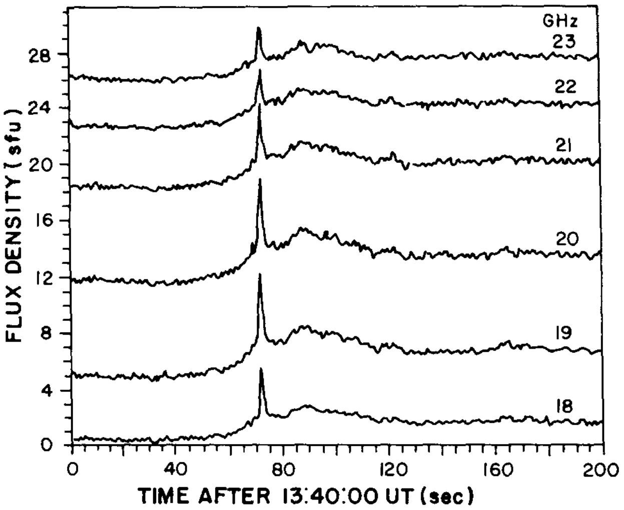

FIG. 1.—Time profiles (18–23 GHz) of the solar burst observed after 13:40:00 UT, on 1990 September 3.

Most of these bursts had a good correlation in time with bursts observed in other frequency ranges. Normally, observations were jointly carried out with Caltech's frequency agile interferometer, operating in the range of 1–18 GHz, and Hard X-Ray Burst Spectrometer (HXRBS) on *Solar Maximum Mission*. Simultaneous observations of millimeter-wavelength bursts in hard X-rays observed by HXRBS is reported elsewhere (Sawant et al. 1993).

Twenty-three impulsive bursts in the range of 18–23 GHz were associated with Hα solar flares of optical importance SN or SF. Plotting our data with those from other observatories we obtained the spectra on both side of the peak frequency for seven simple microwave bursts. The turnover frequencies were in the range of 7–15 GHz.

4. LOW-LEVEL SIMPLE BURSTS AND THEIR SPECTRAL ANALYSIS

We define *low-level simple bursts* as having *e*-folding rise time less than 5 s and a flux density less than 10 SFU, without fine structures superposed in the time profile. In Table 1 are listed properties of the observed low-level simple bursts including the approximate UT of the peak in the time profile, the rise time (t_r) in seconds, the maximum flux ($S_{\max}$) in 22 GHz, and radio spectral index (β) at peak time.

Each spectrum was obtained using the software "Fitting Data to a Straight Line" from Press et al. (1987). This "fitting," to the simple burst spectra, gives the values $\beta_1, \ldots, \beta_5$ with the best error bars $\Delta\beta_1, \ldots, \Delta\beta_5$, corresponding in the time profiles at the following time intervals: (t_1 and t_2) before the peak time, at the peak time (t_3), and two times after (t_4 and t_5). For bursts with lifetime larger than 10 s it is possible to consider more time intervals after and before the peak time.

TABLE 1

LOW-LEVEL SOLAR SIMPLE BURSTS (18–23 GHz)

Date	UT$_{\text{peak}}$	t_r (s)	S_{22} (sfu)	β_{peak}
1989 Jun 30	16 43:08	3.0	3.0	−4.5
1989 Jun 30	16 47:16	3.5	2.0	−4.1
1989 Jun 30	17 43:48	2.0	4.0	−3.2
1990 Sep 3	13 41:12	1.0	3.4	−2.1
1991 Jan 23	13 10:48	4.0	4.0	−2.8

5. INTERPRETATION

5.1. *Spectral Time Evolution*

The time evolution of the spectral index leads to insight into the process of acceleration of the electrons that are responsible for the microwave emission. An impulsive process of acceleration has a spectral index evolution profile with a characteristic signature *soft-hard-soft*. Assuming that the radio emission is due to optically thin, nonthermal gyrosynchrotron emission in a homogeneous source, this behavior is associated with equation (33) from Dulk (1985). As the average energy (ε) rises, the spectral index of the energetic electron distribution (δ) decreases and vice versa. Since the spectral index δ is directly related to the absolute value of the radio spectral index (β) one can use the time evolution of β to investigate the acceleration process.

A criterium is suggested for a classification of the time evolution of the spectral index β (Rosa 1992). The parameter $\Delta\chi$, namely the *hardness width,* has been defined according to the following steps (see Fig. 2*a*):

1. Points *b* and *d* (corresponding to times t_2 and t_4) are joined in order to obtain the straight line *A*;
2. Extending straight line *B* (above *c* and outside its range of uncertainty), the intersection with *A* gives the point *f*,
3. So, we have the values β_f and β_c by means of the perpendicular straight lines *p1* and *p2*, respectively.

Then, the hardness width is given by $\Delta\chi = \beta_f - \beta_c$. Now, a *hardness* can be defined as $H = \Delta\chi / \Delta\beta$, $\Delta\beta$ as described in § 4. Whenever $H > 1$ the acceleration process is classified as "impulsive."

In Figure 2*b* is shown the spectral index time evolution for the impulsive component of the burst in Figure 1. For 80% of the simple bursts the parameter H is greater than 1, suggesting that the acceleration of the energetic electrons, in the case of the simple bursts, is impulsive.

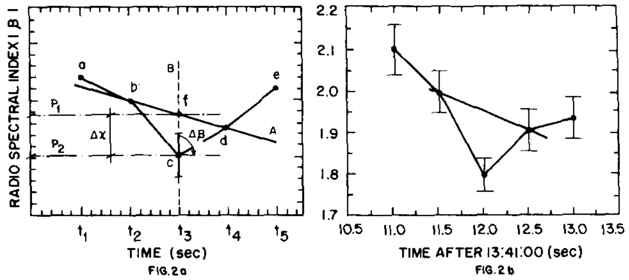

FIG. 2.—(*a*) Time evolution of microwave spectral index, in absolute value, and the criterium for estimating the *hardness*. (*b*) Time evolution of microwave spectral index, in absolute value, for the impulsive simple burst component of Fig. 1.

5.2. *Source Parameters*

Absolute values of β and their time evolution also suggest a nonthermal emission mechanism for the microwave source. Therefore, assuming the nonthermal gyrosynchrotron emission mechanism for generation of simple microwave burst and using equations (35) and (39) of Dulk (1985), equation (12) of Holman (1985), and considering appropriate input parameters, we obtain the peak frequencies between 8.4 and 11.0 GHz, and the source parameters (Rosa 1992): $h \simeq 2.4 \times 10^3$ km, $B \simeq 307$ G, and $N_\epsilon < 8.8 \times 10^9$ cm^{-3}, where N_ϵ is energetic electrons.

6. DISCUSSION AND CONCLUSION

As discussed earlier, turnover frequencies of the simple bursts under consideration were obtained in the range of 7–15 GHz, and thus observed spectra were well in the optically thin part. This along with the high spectral resolution observations permits us to determine the spectral index more accurately than those figures quoted earlier in the literature.

The values calculated from observed spectra are between -1.0 and -4.0, with an average of -2.8. The theoretical analysis using software developed by Rosa (1992) gave an average spectrum with a value $\beta = -2.6$, in good agreement with observation. This average value leads to the estimate the spectral index of the energetic electron distribution (δ) to ~4.5. According to Dulk (1985) the optically thin thermal emission requires a higher value for δ (~8). The value 4.5 obtained here favors the nonthermal emission mechanism.

Based on the studies of five low level simple bursts observed in the range of (18–23) GHz with high spectral resolution we reach the following conclusions:

1. An average flux density ~3.5 SFU, average *e*-folding rise time ≤ 3 s, and correlation with Hα flares SF or SN suggest that simple bursts are a counterpart of EFB.
2. Spectral behavior suggests a nonthermal emission mechanism during the rise phase of the burst and an *impulsive* production/acceleration process for the energetic electrons.
3. The solar microwave burst, if from homogeneous source, is due to energetic electrons with density less than 8.8×10^9 cm^{-3}, in a region where the magnetic field is ~300 G.

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