Bull. astr. Soc. India (1981) 9, 291–296

Magneto-ionic conditions and energetics of simultaneous solar microwave bursts at 2.8, 10 and 19.3 GHz on 1980 June 4

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Received 1981 September 5; accepted 1981 October 15

Abstract. Simultaneous microwave bursts were observed at 2.8 and 19.3 GHz at Ahmedabad and at 10 GHz at Hyderabad on 1980 June 4. The peak of the burst occurred at 0836, 0838 and 0840 UT at 19.3, 10 and 2.8 GHz respectively, showing progressive delay from high to low frequencies. Following the theoretical work on magneto-ionic conditions for emission and energetics of electrons during solar flares we estimate the magnetic field to be $\sim$ 900 gauss, energy of the electrons to be 1.4 MeV and angular size of the burst source to be $\sim$ 8 arcsec. The brightness temperature of the source was 1.2×10^4 K at 19.3 GHz and 2×10^6 K at 2.8 GHz as a result of plasma heating in association with x-ray events.

Key words : microwave event—solar radio burst—coronal magneto-ionic conditions—energetics of electron plasma—solar atmosphere

1. Introduction

A number of solar flares were observed from Region 2490 on the solar disk, which was located at S14, L358 on 1980 June 4. Two x-ray events (M7 and M4) occurred in this region on that day though optically these flares were weak. However, they produced strong radio bursts, particularly in the microwave range. Important parameters of the microwave burst source have been deduced in this paper. As the bursts show symmetrical rise and fall characteristic, it has implication for the radio emission mechanism as discussed by Pick (1980).

2. Microwave observations

Two microwave Dicke-type radiometers at 2.8 GHz and 19.3 GHz are operating at Ahmedabad and a similar one at 10 GHz at Hyderabad as part of international solar maximum year program for the study of the solar flares and the solar activity. Corresponding to the flare at 0654 UT, a small microwave burst at 2.8 GHz with peak flux of 95 solar flux unit (sfu) at 0656 UT was recorded. However, after this small event, a major microwave burst occurred both at 2.8 GHz and 19.3 GHz as shown in Figures 1 and 2. The event began at 0826 and 0823 UT and reached maximum at about 0840 and 0836 UT respectively. The peak flux was estimated to be about 1600 sfu at 2.8 GHz and 10 GHz, and $\sim$ 515 sfu at 19.3 GHz. The brightness temperature of the source with this flux works out to be 1.2×10^4 K at 19.3 GHz, 2×10^6 K at 2.8 GHz and 10 GHz. The burst record at 10 GHz is not shown because the instrument had no proper sun-tracking facility and so continuous record could not be obtained.

Another interesting feature to be noted is that the peak of the microwave burst occurred some 4 min earlier at 19.3 GHz than at 2.8 GHz, with 10 GHz peak falling in between. The time of the peak flux at 2.8 GHz was extrapolated taking

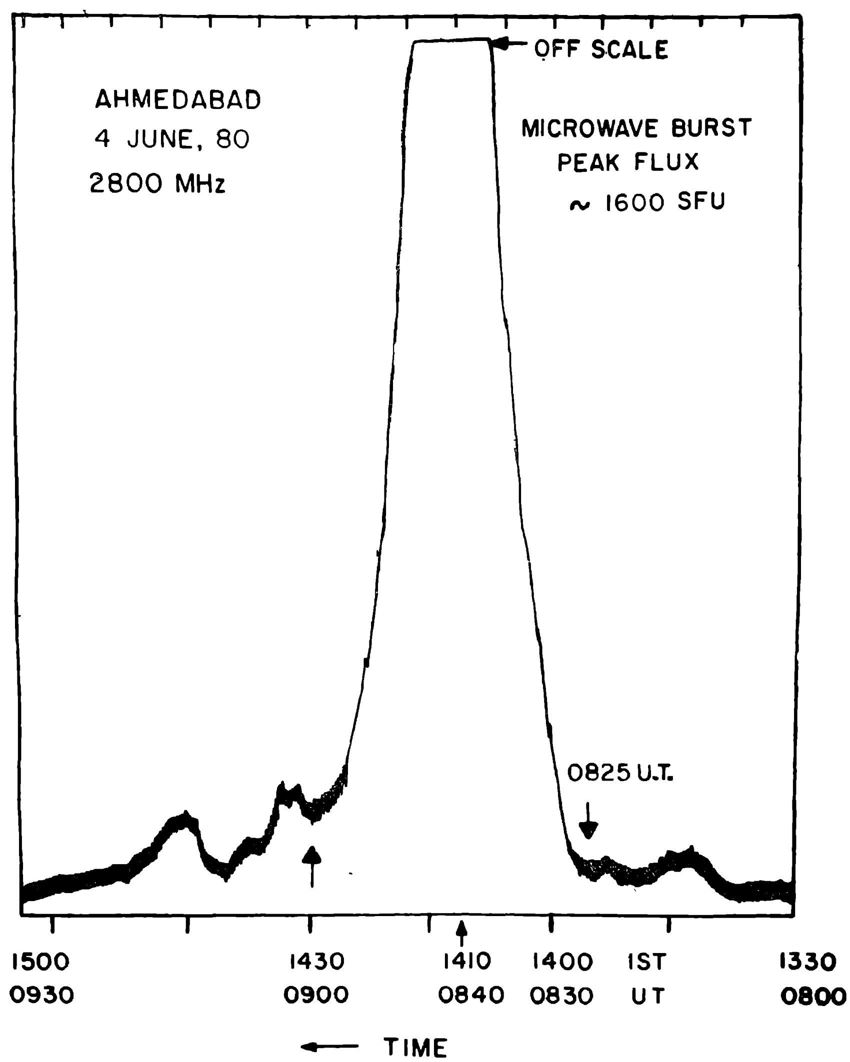

Figure 1. Tracing of intense microwave burst recorded at 2.8 GHz at Ahmedabad on 1980 June 4 starting at 0807 UT and reaching maximum at 0840 UT. The burst intensity has gone off scale near burst peak which is estimated to be of the order of 1600 sfu.

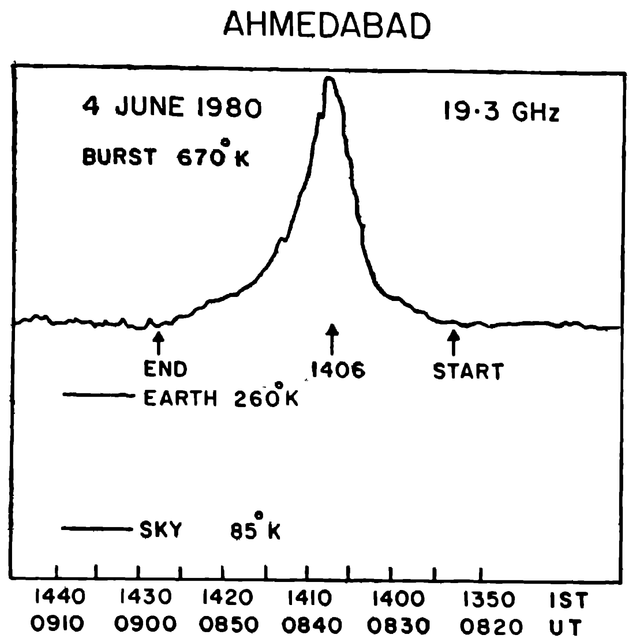

Figure 2. Simultaneous solar burst recorded at 19.3 GHz at Ahmedabad on 1980 June 4 starting at 0817 UT and reaching maximum at 0836 UT. The peak flux was of the order of 500 sfu.

into account the simple rise and fall nature of the burst as recorded at 19.3 GHz. This shows systematic shift in time of maxima of flux at each frequency. This may be attributed to a progressive shift of the position of the source away from the sun, thus effectively reducing the magnetic field associated with the source. Table 1 gives the relevant burst characteristics.

Table 1. Microwave burst characteristics observed simultaneously at 2.8, 10 and 19.3 GHz on 1980 June 4.

Frequency GHz	Start UT	Max UT	End UT	Rise time min	Decay time min	Remarks
2.8	0825	0840	0900	15	20	Symmetric rise and fall type
10	0825	0838	—	13	—	,,
19.3	0823	0836	0858	13	22	Little asymmetric

It can be seen that the rise time is a little larger at 2.8 GHz than at 19.3 GHz and the decay time also is a little shorter at 2.8 GHz than at 19.3 GHz though these times are comparable. This may be because in the non-thermal model for the centimetre region, the non-radiative collisional losses (fast electrons colliding with ambient electrons) are much more important than the bremsstrahlung emission (Ramaty *et al.* 1978).

3. Discussion

In the extended wavelength region of solar burst radiation from 1 m to 1 cm, two distinct components are discerned, one from 1 m to 10 cm, and the other from 10 cm to 1 cm. The radiation of the low frequency component almost always extends to metre wavelengths and that of the high frequency component on occasion extends into millimetre range (Guidice & Castelli 1975).

The emission mechanism for the low frequency component is generally accepted as synchrotron radiation by relativistic electrons (> 1 MeV) in the coronal region above the flare or some other disturbance. The region in which this radiation takes place is characterized by relatively low electron density ($\sim 10^8$ cm^{-3}) and low magnetic fields ($\sim$ 5–10 gauss). The mechanism for centimetre radiation of solar bursts is considered to be gyrosynchrotron radiation from non-relativistic or barely relativistic electrons (< 1 MeV) in strong magnetic fields ($\sim$ 1000 gauss) (Takakura 1960, 1967).

Figure 3 shows a log-log plot of the peak flux density of the burst observed at various fixed frequencies starting from 245 MHz to 19.3 GHz. The 2800 MHz and 19.3 GHz points are plotted from the Ahmedabad data and the remaining ones are taken from the solar-geophysical data bulletins issued from Boulder, USA. It can be seen that the peak flux decreases at first from 245 MHz, reaching minimum at 606 MHz. The burst intensity then increases to reach a maximum at 8.8 GHz, after which the flux shows a steep decline. The shape of the spectral curve is GC type of intensity 3 as defined by Guidice & Castelli (1975).

The magneto-ionic conditions of the burst source and the electron energies involved in this microwave event can be estimated from multi-frequency observations

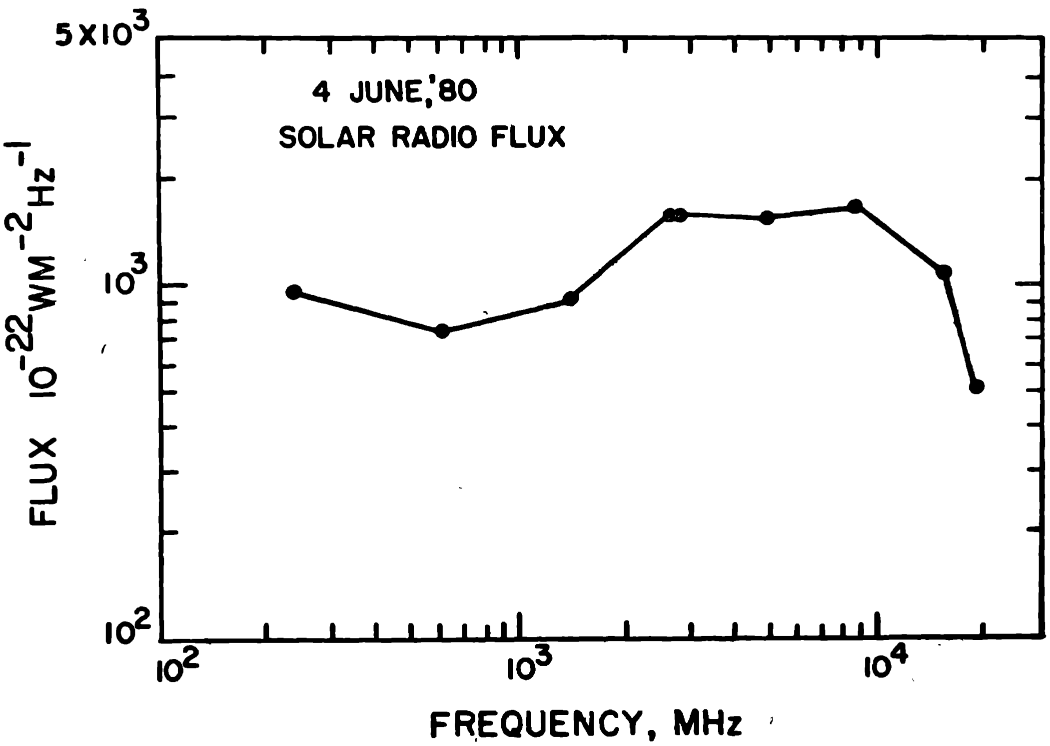

Figure 3. Log-log plot of peak burst intensity as a function of frequency from fixed frequency radiometers recorded on 1980 June 4 including the burst data shown in Figures 1 and 2. Data at other frequencies were obtained from Solar Geophysical Data, Boulder. The maximum flux is seen to occur at 8.8 GHz.

since Takakura (1967) has shown that the centimeter spectrum observed on the earth will be broadly peaked at a frequency f_m equal to about 3 to 4 f_H, where f_H is the gyro-frequency. Since f_H is related to the magnetic field by $f_H = 2.8\ H_\perp$, f_m will be approximately given by

$$f_m \approx 3.5\ f_H = 9.8\ H_\perp \qquad \ldots(1)$$

Thus, in the present case, $f_m = 8800$ MHz and therefore $H_\perp \approx 900$ gauss, which is the magnetic field perpendicular to the electron velocity. The energy of the electrons may also be estimated as shown by Guidice & Castelli (1975)

$$f_m \approx 4.7\ H_\perp E^2, \qquad \ldots(2)$$

where E is in MeV.
Putting $f_m = 8800$ MHz and $H_\perp = 900$ gauss, we get

$$E^2 \approx 2 \text{ and } E \approx 1.4 \text{ MeV} \qquad \ldots(3)$$

which is mildly relativistic. Such energies for electrons are attained during the second phase of acceleration in a solar flare, the first phase of acceleration lasting not more than a fraction of a minute (Pick 1980). The more recent approach to microwave radiation assumes that the electrons are heated in bulk and correspond to a Maxwellian energy distribution (Ramaty *et al.* 1978; Dulk *et al.* 1978). Both x-ray and microwave observations are satisfactorily explained if the emitting region is dense ($\sim 10^{10}$ electrons cm^{-3}), hot ($\sim 10^8$ K) and compact ($\sim$ 14 arcsec) with a magnetic field of a few hundred gauss (Dulk *et al.* 1978).

We can also estimate the angular size of the burst source using the relation given by Kellermann (1966), but with appropriate modifications to solar conditions :

$$f_m \approx 24\, H_\perp^{1/5} \cdot (S_m/\phi^2)^{2/5} \qquad \ldots(4)$$

where ϕ is the source size in arcmin and S_m is the observed solar flux in sfu. Putting $f_m = 8800$ MHz $H_\perp = 900$ gauss and $S_m = 1600$ sfu, we obtain $\phi \approx 8$ arcsec which is in good agreement with the values obtained by Alissandrakis & Kundu (1975) and Pick (1980).

4. Conclusions

Useful burst source parameters like the magnetic field, energy of electrons and source size have been obtained for the event observed simultaneously at three microwave frequencies on 1980 June 4. They are in good agreement with measurements made elsewhere with interferometer techniques.

Acknowledgements

The cooperation of the staff in the maintenance of the instruments is very much appreciated. The work at Ahmedabad is supported by the Department of Space at the Physical Research Laboratory and Space Applications Centre, and at Hyderabad by the University Grants Commission.

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