OBSERVATIONS ON THE TIME AND FREQUENCY STRUCTURE OF SOLAR DECAMETER RADIO BURSTS

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Abstract. Solar radio bursts were observed with a 4-channel radiometer and polarization analyser at wavelenghts around 12 m. The time and frequency resolutions were 10 ms and 100 kHz respectively. Observations on the duration, time profile and frequency splitting are described.

1. Introduction

It has been recognized for many years that observations on the microstructure of solar radio bursts with high temporal and frequency resolution radiometers will give valuable information on the process of burst generation and the physical state of the corona. Many such observations were made by de Jager and Van't Veer (1958), Elgaroy (1961), de Groot (1966) and others in the frequency region 200 MHz and above. It is only recently the exploration of the lower end of the radio spectrum began with the observations of Ellis (1969a) and others. We have already reported some of our results on the time splitting and frequency drift of the storm bursts in the 25 MHz region, Sastry (1971, 1972). In this paper we present results of our further investigations on the time and frequency structure of the radio bursts.

2. Equipment

The observations reported here were made with two instruments. The first one was a 4-channel spectrum analyser. The antenna system for this instrument consists of 72 full wave dipoles and with a gain of the order of 24 db. The bandwidth and time constant of the receivers were 13 kHz and 10ms respectively. The center frequency was 25 MHz and the channel separations ranged from 80–200 kHz. The second instrument was a polarization analyser and the antenna system for this one consists of 8 pairs of half wave dipoles at a wavelength of 12 m. In each pair the two dipoles were oriented in mutually perpendicular directions (EW and NS). The electronic set up was of a conventional design and the final recorded output was the difference between the R.H. and L.H. circular components. The spectral and polarization data were recorded on a four channel Ediswan pen oscillograph which has a frequency response of about 90 Hz. The paper speeds used were in the range 0.75–3.00 cm s^{-1}.

3. Observations

The data used in the present analysis were recorded during the period March 1969 to

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August 1971. The equipment was operated during times of enhanced solar radio emission and three types of activities are recorded. These are (1) background continuum enhancement only with irregular variations, (2) short period and narrow band bursts superimposed on the enhanced background, and (3) short period and narrow band bursts without accompanying continuum enhancement. In all cases the time of enhanced radio emission lasted from about an hour to 4 or 5 days. In a majority of cases when we recorded enhanced radio emission at 25 MHz the Hiraiso observing station of the University of Tokyo in Japan reported noise storms at 200 MHz. It should be pointed

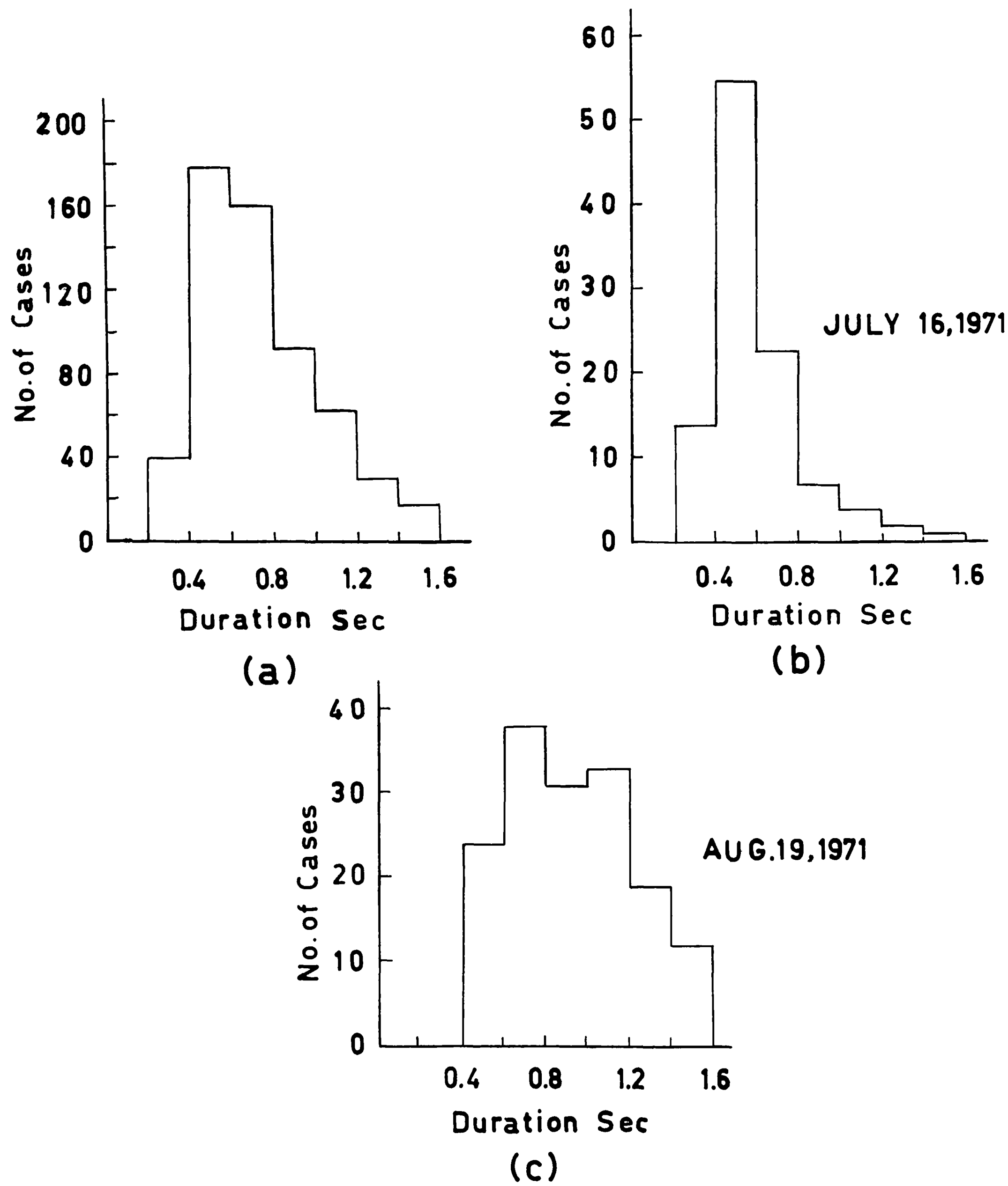

Fig. 1. Distribution of the half power durations of storm bursts at 25 MHz. (a) All isolated bursts that were recorded during the period March 1969 to August 1971. (b) Isolated bursts recorded on July 16, 1971. (c) Isolated bursts recorded on August 19, 1971.

out that due to the limited total bandwidth of our instrument it is not possible to identify the various types of bursts recorded. The present study uses only those isolated bursts which are of short duration (⩽1.5 s) and narrow bandwidth (⩽300 kHz). Also about 30% of these bursts are circularly polarised. Since bursts with this type of characteristics are known to occur in noise storms in the meter wavelength region, we refer to them as storm bursts. We have investigated the following aspects of the storm bursts: (a) duration and bandwidth; (b) time profile; (c) frequency splitting and the results are presented below.

A. DURATION

The measurement of duration and its dependence on various bursts parameters like the frequency, bandwidth, polarization and intensity is important since the duration depends on the type of damping mechanism that is in operation. Only isolated bursts with simple rise and fall were used for duration measurements. The distribution of the number of bursts with various values of half power duration is shown in Figure 1a. The histogram shows that the average value of the half power duration lies between 0.5 and 1.0 s. and that the number of bursts gradually decreases as the duration increases. It is found that the characteristics of this histogram change from one storm to

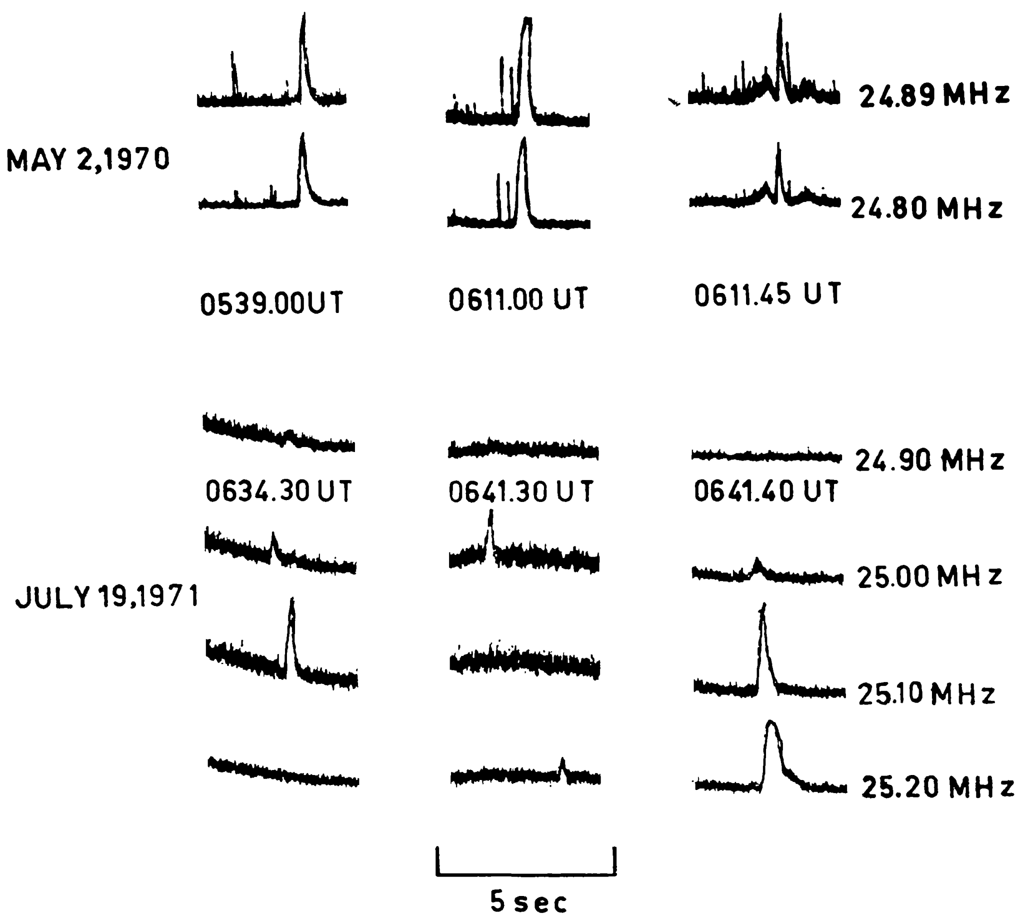

Fig. 2. (a) Typical examples of spike bursts at 25 MHz.

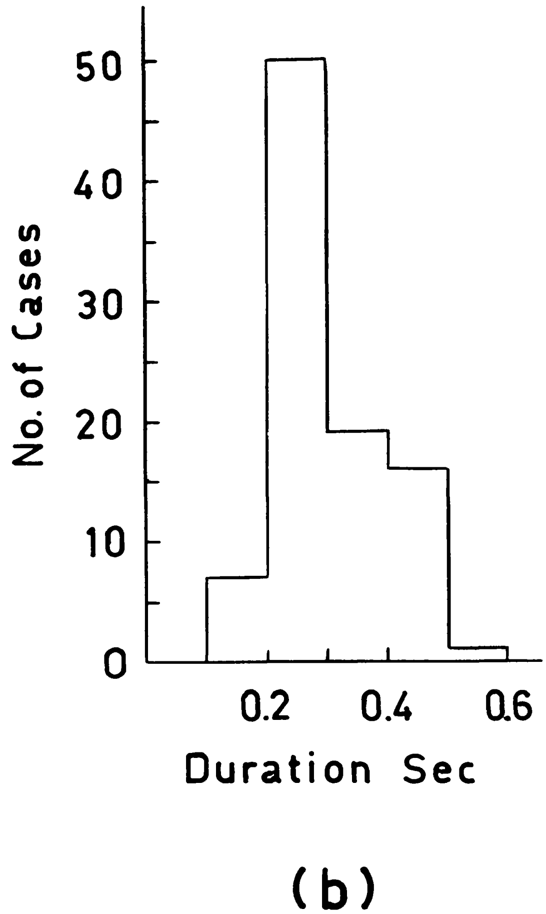

Fig. 2. (b) Distribution of the durations of spike bursts.

another as illustrated in Figure 1b and 1c. It can be seen that on July 15, 1971 there is a well defined peak around 0.5 s whereas during another storm period i.e. on August 19, 1971 the peak is quite broad and extends from 0.5–1.2 s. We also found that sometimes the character of the histogram changes from day to day in a particular storm. De Jager and Van't Veer (1958) also obtained similar results at 200 MHz. We have investigated the relationship between the duration and the following characteristics of the bursts: (1) bandwidth, (2) polarization, (3) amplitude. It is found that the narrow band bursts tend to have shorter durations and the distribution of durations in the case of polarized bursts is very broad. It would appear that there is a weak positive correlation between the amplitude and the duration. The linear correlation coefficient between the amplitude and duration is found to be $+0.40 \pm 0.10$.

There is a distinct class of bursts of very short duration detected in the frequency range 150 MHz and above which are known as spike bursts. No measurements on this type of bursts have been previously reported, at low frequencies. We have detected several spike bursts in the 25 MHz region and typical examples are illustrated in Figure 2a. These bursts are characterized by an extremely sharp rise and fall and their durations are very small. It can be seen from the histogram of Figure 2b that a majority of these bursts have half power durations of the order of 200–300 ms. We have never observed these bursts in groups of more than two and also in many cases they are not associated with type III bursts.

We have determined the bandwidths of a large number of bursts using our four channel records. It should be pointed out that our band width measurements are not exact due to the 100 kHz separation between channels. Table I gives the distributions

TABLE I

Distribution of the bandwidths of storm bursts at 25 MHz

Type of burst	No. of cases with bursts in 4 channels BW ⩾ 300 kHz	No. of cases with bursts in 3 channels BW 200–300 kHz	No. of cases with bursts in 2 channels BW100–200 kHz	No. of cases with bursts in 1 channel BW ⩽ 100 kHz	Total number of cases
All bursts	127 (18 %)	170 (24 %)	213 (31 %)	190 (27 %)	700
Spike bursts	7 (10 %)	18 (%28)	22 (36 %)	17 (26 %)	64

of the number of bursts with various estimated bandwidths for all bursts and also for spike bursts only. It appears that in a majority of cases the bandwidth is less than 300 kHz both for normal and spike bursts.

B. TIME PROFILE

An examination of all the isolated bursts recorded by us showed that there are essentially four types of profiles and these are illustrated in Figure 3. In the first type, shown

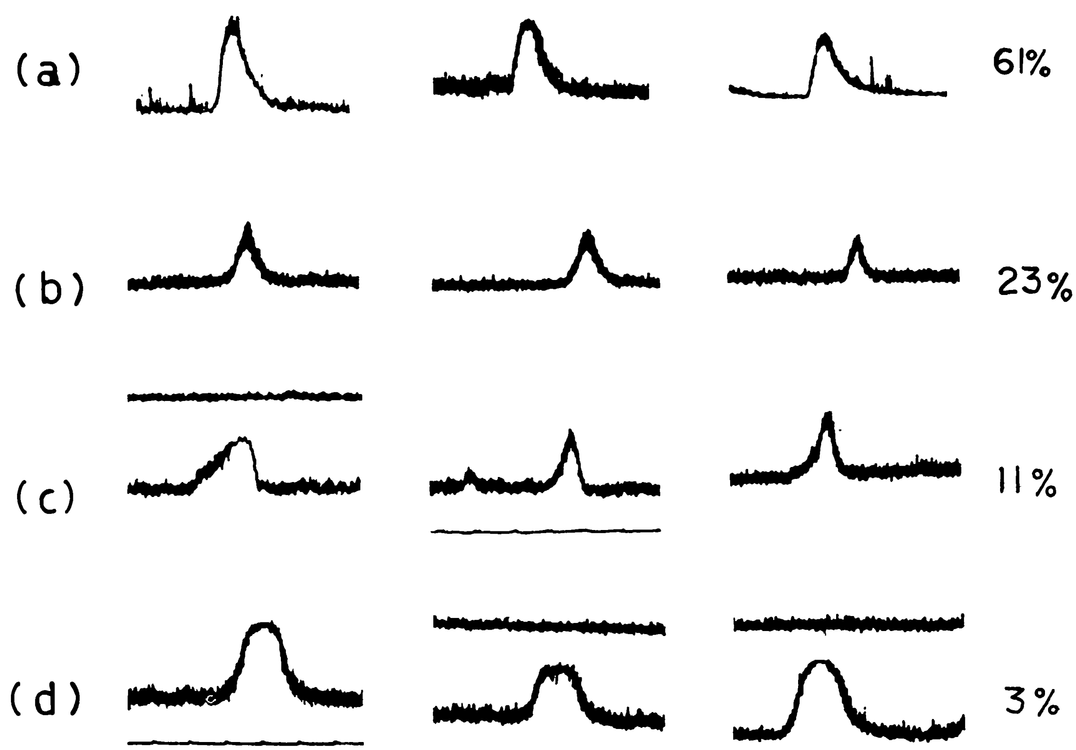

Fig. 3. Time profiles of storm bursts at 25 MHz. One second time markers are shown in the central example of (c) and the first example of (d).

in Figure 3a, there is a steep rise to the maximum followed by a gradual decay. In a typical storm about 61% of the bursts have this kind of profile. The second type, shown in Figure 3b, is a triangular burst in which the rise and decay times are approximately equal. It is found that about 23% of the total number of the bursts have a triangular profile. The third type, shown in Figure 3c, is the reverse of the first in the sense that in this case there is a gradual rise and steep decay. In the fourth type, shown in Figure 3d, the peak is quite broad. The possibility that this kind of profile is due to receiver saturation has been carefully examined, and rejected. The occurrence of the last two types of profiles was rare and together they account for only 14% of the total number of bursts.

C. FREQUENCY SPLITTING

The existence of a characteristic type of storm burst made up of two narrow band components separated in frequency by a small interval was first reported by Elgaroy (1961) in the 200 MHz region. The only detailed observations on this type of frequency splitting at long wavelengths are those of Ellis and McCulloch (1966) although the phenomenon was observed by Warwick and Dulk (1969) and Boischot *et al.* (1971). We have detected several split pairs in the 25 MHz region. Almost all the split pairs

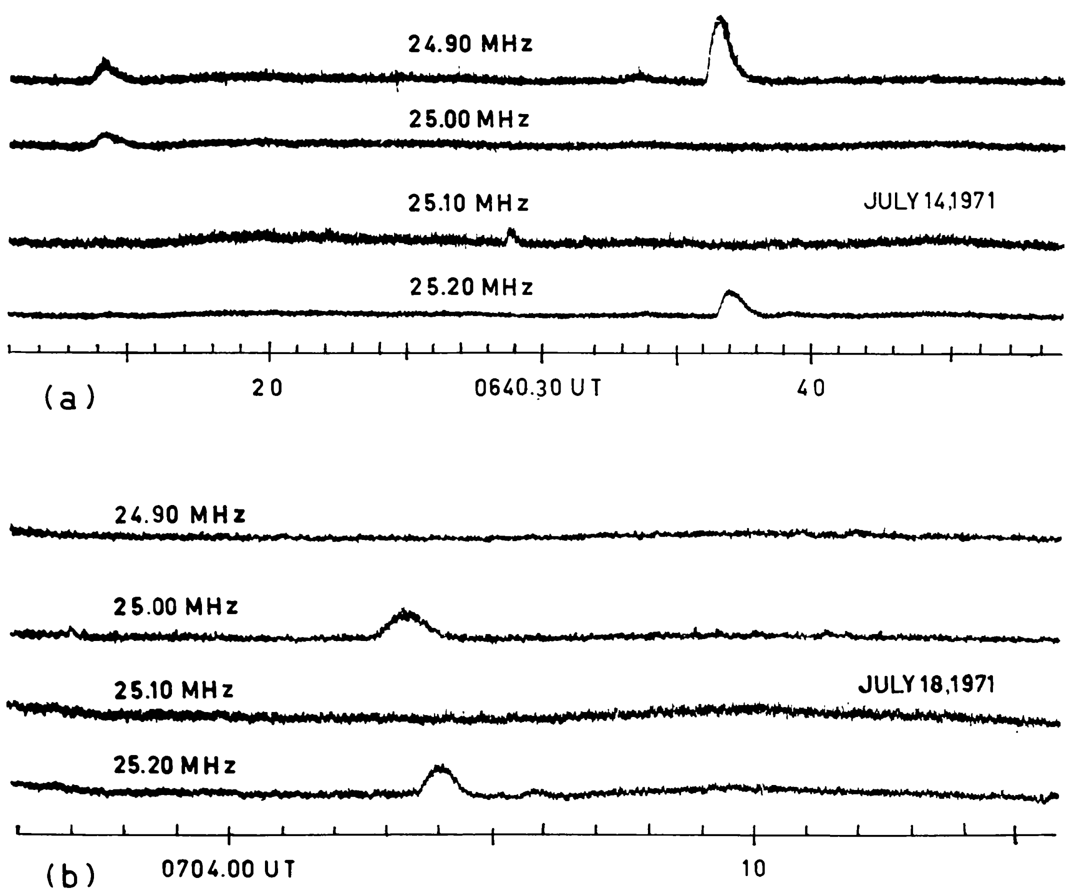

Fig. 4. Typical examples of split pairs. The time markers are at intervals of one second. Note that the recording speed of (b) is twice that of (a).

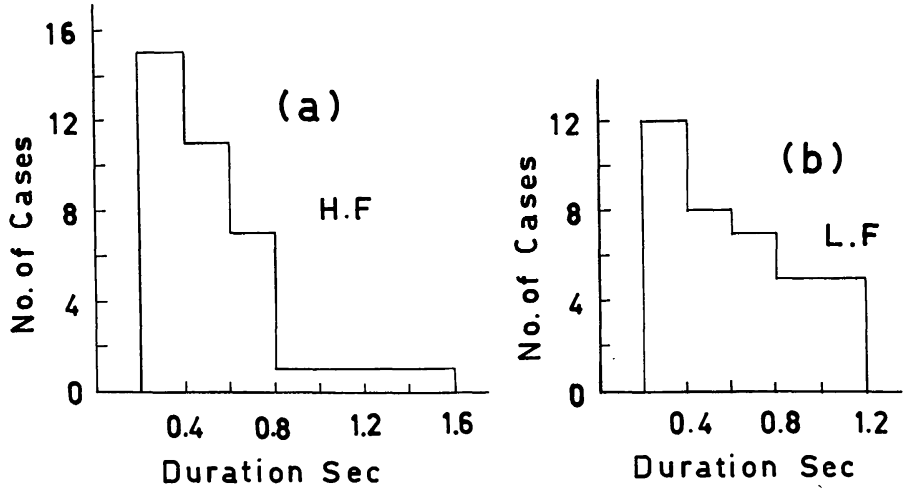

Fig. 5. Distribution of the durations of (a) high frequency and (b) low frequency elements in split pairs.

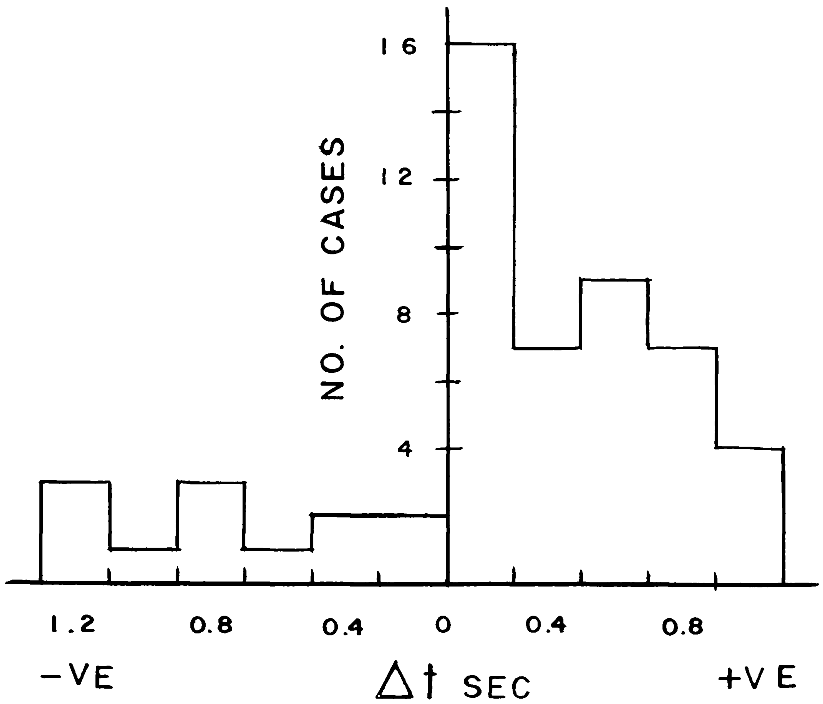

Fig. 6. Distribution of the difference in starting times Δt between the two components in split pairs.

detected by us are isolated occurrences. The time interval between the occurrence of two successive split pairs was generally of the order of few tens of seconds although in some cases this can be much lower. Typical examples of split pairs are shown in Figure 4. It can be seen in Figure 4a that a pair of bursts occurred in the 24.90 and 25.20 MHz channels almost simultaneously but not in the central two channels. The frequency separation is less than or equal to 300 kHz. In Figure 4b an example is shown where the frequency separation is of the order of 200 kHz. We found that in some cases the split pairs were superimposed on the wideband enhanced background. The histograms in Figures 5a and 5b show the distribution of the half power durations of both the high and low frequency elements in split pairs and that the durations lie in the range 0.3–0.8 s. It is found that in a particular event the duration of either element can be larger and that the high frequency element is generally more intense. The difference in the starting times Δt between the two elements in a split pair is determined for all the events recorded. The sign of Δt is taken to be positive if the low frequency element appears first. The histogram in Figure 6 shows that the low frequency element appears first in a majority of cases. We have looked for differences in the time profiles in the two elements of a split pair. For this purpose the time intervals t_1 and t_2 at half intensity were measured and the difference $t_1 - t_2$ is plotted in Figure 7. One can see that the negative values of $t_1 - t_2$ are more frequent in the case of the high frequency elements which implies that the decay times tend to be larger. In the case of the low frequency elements there are approximately equal number of positive and negative values of $t_1 - t_2$. It is also found that in a few cases the time profile of the high frequency element appears to be the mirror image of the low frequency element. Figure 8 illustrates this phenomenon. It can be seen in Figure 8a that there is a steep rise followed by a gradual decay of the intensity in the case of the

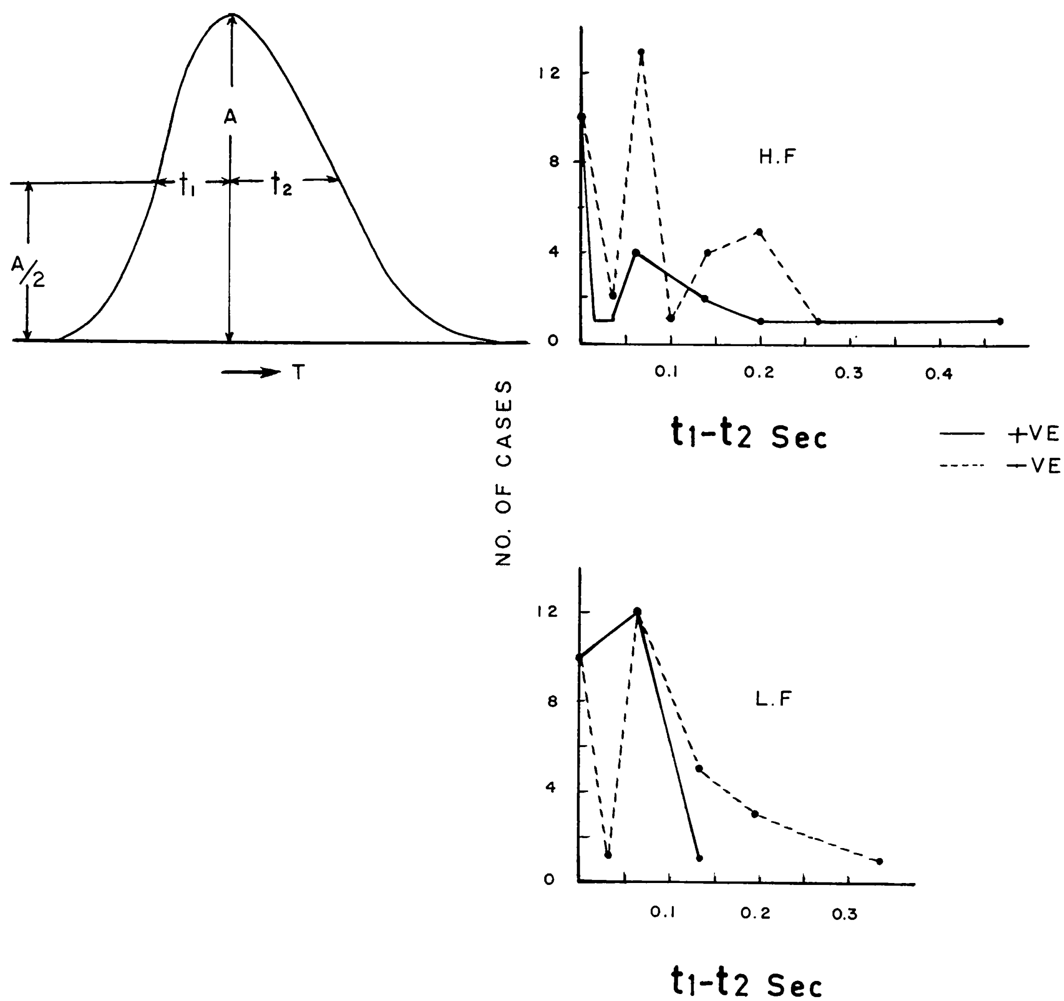

Fig. 7. Asymmetry in the time profiles of the high and low frequency elements in split pairs.

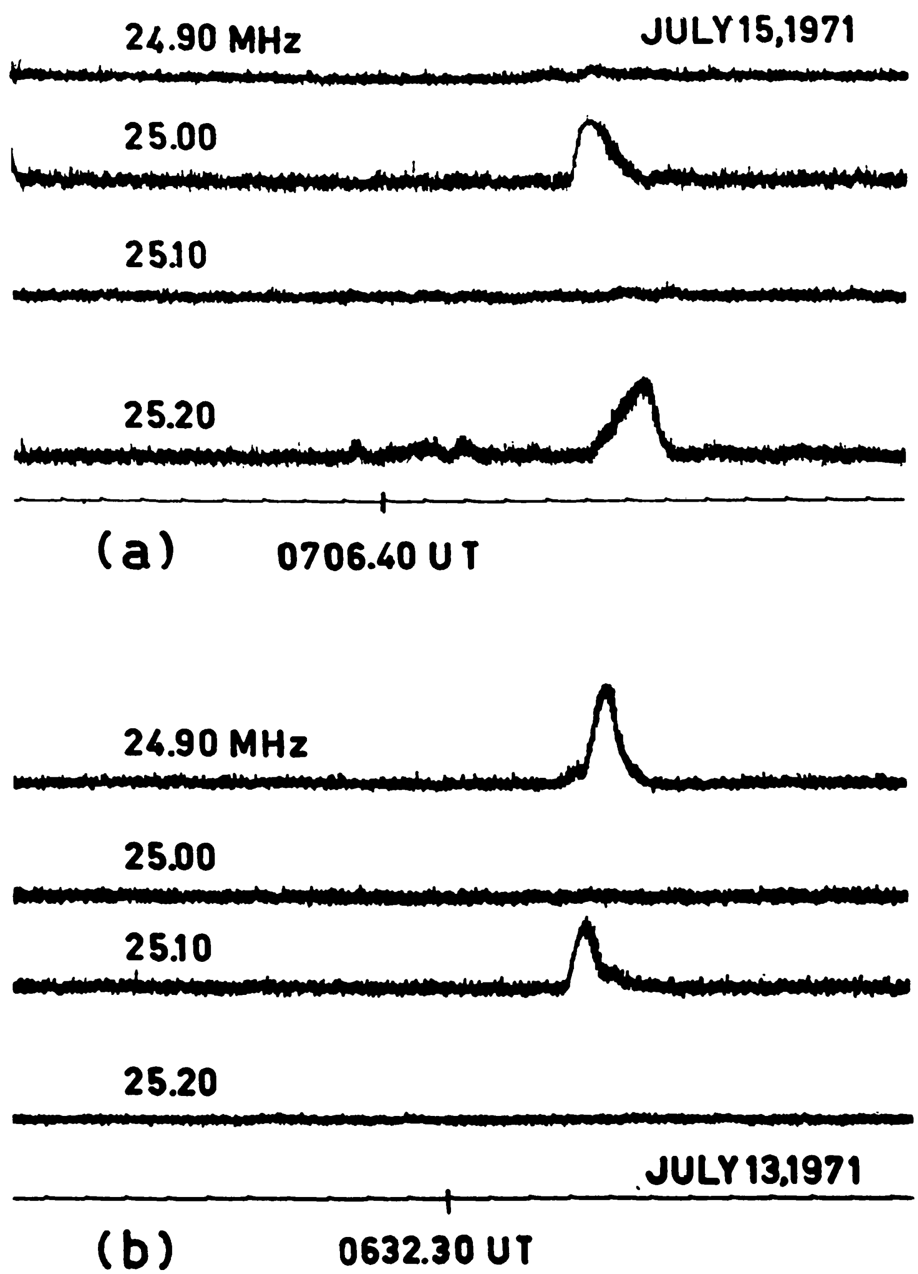

Fig. 8. Examples of split pairs in which the time profile of the high frequency element is the mirror image of the low frequency element. The time markers are at intervals of one second.

burst at 25.00 MHz whereas the reverse is true for the burst at 25.20 MHz. A careful examination of Figure 8b reveals that the small rise in intensity which occurred at the beginning of the burst at 24.90 MHz was repeated at almost the end of the burst at 25.10 MHz.

It is well known that solar radio bursts sometimes exhibit double structure in time. Our observations on the double bursts (Sastry, 1971, 1972) showed that the splitting in time is probably inherent to the generating mechanism itself and is neither an echo phenomenon nor is it due to magneto-ionic splitting. We found that several

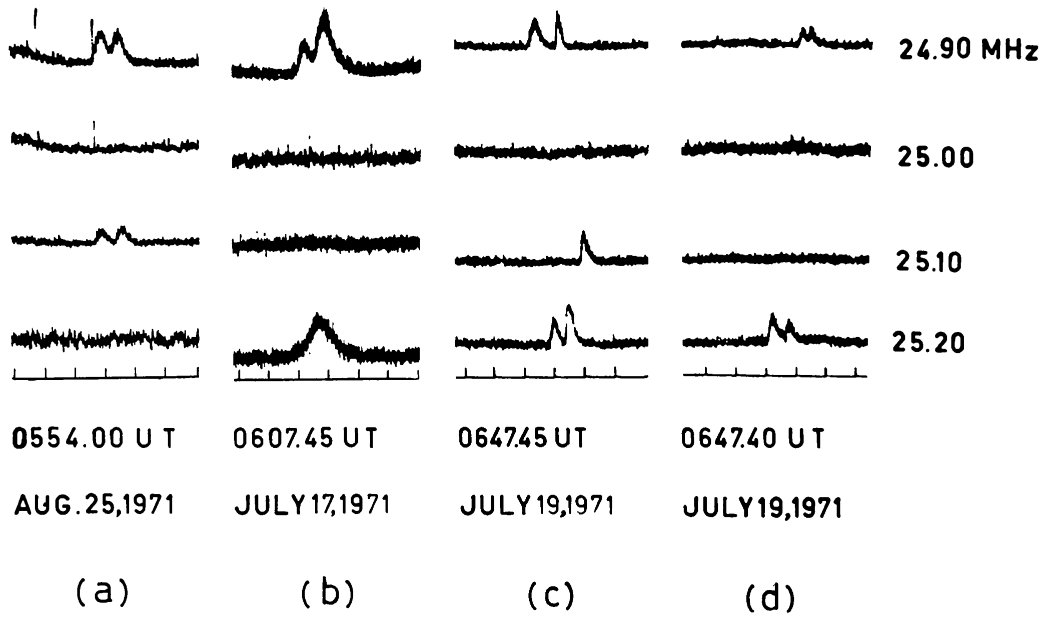

Fig. 9. Examples of radio bursts which exhibit both time and frequency splitting. The time markers are at intervals of one second.

bursts which exhibit time splitting also show frequency splitting. Typical examples are shown in Figure 9, where it can be seen in (a), (c) and (d) typical double bursts with frequency splitting. In Figure 9b is shown a case where there is a double burst at the low frequency (24.90 MHz) and a single burst at the high frequency (25.20 MHz).

4. Discussion

The observed durations of storm bursts in the 200–400 MHz region were found to be in the range 0.2–0.4 s (Elgaroy and Eckhoff, 1966). Since these values are much larger than the collisional damping times for the plasma waves, for temperatures of the order of 10^6 K, Takakura (1963) suggested that the durations are controlled by the time required for the physical disruption of the electron streams responsible for exciting the plasma waves. On this basis one can derive the velocity of the electron streams from the observed durations. In the present case the stream velocity at the 25 MHz plasma level should be about 8×10^3 km s^{-1}. Since the stream velocity should be a few times the thermal velocity for the plasma waves to propagate the temperature at the burst source turns out to be approximately 0.3×10^6 K. On the assumption that the collisional damping times control the durations at decameter wavelengths the observed durations at 25 MHz yield temperatures of the order of 10^6 K which is the usually accepted value. It has been assumed that the bandwidth of the storm bursts is due to Doppler broadening (de Jager and Van 't Veer, 1958). For a temperature of 10^6 K the expected bandwidth at 25 MHz is approximately 0.9 MHz. The observed bandwidth of 300 kHz is much lower than this and so Doppler broadening is probably not the mechanism responsible for the bandwidth at decameter wavelengths.

The observed time profile of a majority of the storm bursts at decameter wavelengths, shown in Figure 4a, is significantly different from that found in the very high frequency region by Elgaroy (1961) and de Groot (1966). This is probably due to the smaller collision frequency at the higher levels of the corona. De Jager and Van't Veer (1958) derived the theoretical time profiles of singly occurring bursts emitted by small discrete clouds in the solar corona. The process of burst generation was excitation and subsequent decay of plasma oscillations. They assumed that the cloud is excited in its center by some unknown cause at time $t=0$ and that the excitation progresses spherically outward with a speed β. They further assumed that the ratio between the intensities of excitation of an element excited at $t=t_1$ and that of the central element is proportional to $t^{-n}(n\geqslant 0)$, and also that the excitation continues till the moment $t=T$ when the frontiers of the cloud are reached. With these assumptions the intensity $I(\tau)$ observed at time τ from a cloud excited at time t is given by

$$I(\tau) = 4\pi\alpha\beta \int_0^{t_1} t^{2-n} e^{-\lambda(\tau-t)}\, \mathrm{d}t,$$

where α is the intensity emitted by one unit volume element and λ is the decay constant equal to the collision frequency. The solution of the above integral for $n=2$ is of the form

$$\frac{1}{\lambda}(1-e^{\lambda\tau}) \quad \text{for} \quad \tau \leqslant T$$

and

$$\frac{e^{-\lambda\tau}}{\lambda}(e^{\lambda\tau}-1) \quad \text{for} \quad \tau > T.$$

The values of $I(\tau)$ computed on the assumption that the product λT is equal to unity are plotted in Figure 10. The observed time profile of a majority of the bursts is also shown for comparison. The unit of time in both cases is T. It can be seen that the agreement between the theoretical and the observed time profiles is reasonably good. In this interpretation the excitation mechanism, although unknown, is assumed to originate in the cloud itself, and so the radio bursts should not show any frequency drift. It is found that a majority of the storm burst at decameter wavelengths do not show any frequency drift (Sastry, 1972).

There is good agreement between the results of the present observations and those of Ellis and McCulloch (1967) on the frequency splitting of storm bursts, although a large portion of the split pairs detected by them occurred in groups or chains whereas almost all the pairs recorded by us were isolated occurrences. According to Ellis (1969b) the most probable explanation of the frequency splitting is the excitation of the plasma radiation by the coronal electron stream at the adjacent frequencies $f_1=f_\mathrm{p}$ and $f_2=(f_p^2+f_\mathrm{h}^2)^{1/2}$, the upper hybrid resonance frequency, where f_p and f_h are the plasma and gyro frequencies respectively. If this is the case the coronal magnetic field

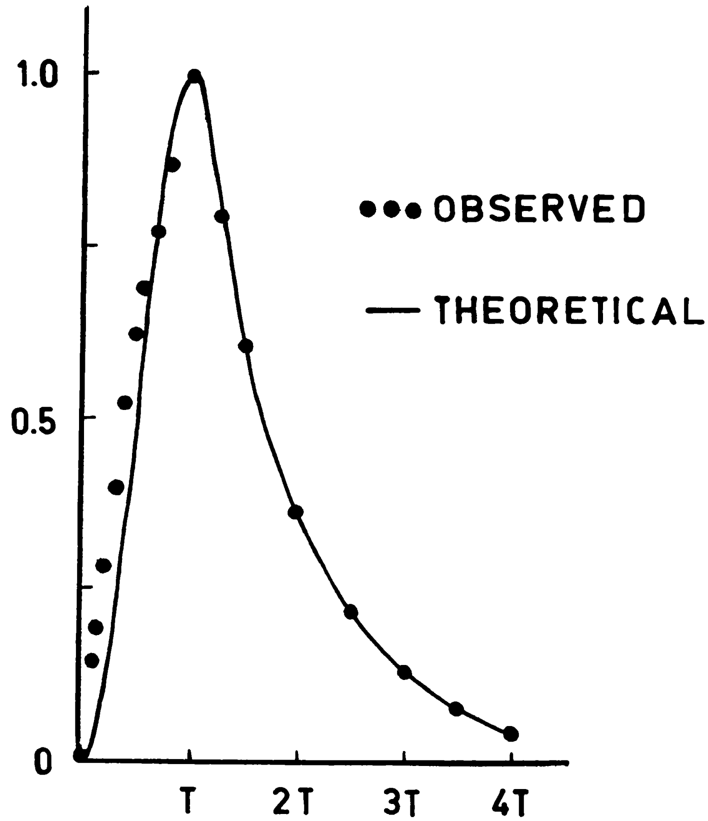

Fig. 10. Comparison of the observed and theoretical time profiles of storm bursts.

strength can be derived from the observed frequency intervals, and in the present case it turns out to be about 1 G at the 25 MHz plasma level. It is difficult to explain on this basis the earlier start of the low frequency component and also the significant difference in the time profiles of the two components. It is possible that the bursts may be due to the excitation of two adjacent clouds of slightly different electron densities as pointed out by Elgaroy (1961).

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