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Time Structure of Solar Decametre Type III Radio Bursts

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Abstract. The time structure of solar radio decametre Type III bursts occurring during the periods of enhanced emission is investigated. It is found that the time profiles can take a variety of forms of which three distinct types are the following: (1) profiles where the intensity rises to a small but steady value before the onset of the main burst, (2) the intensity of the main burst reduces to a finite level and remains steady before it decays to the base level, (3) the steady state is present during the rise as well as the decay phase of the main burst.

It is shown that these profiles are not due to random superposition of bursts with varying amplitudes. They are also probably not manifestations of fundamental-harmonic pairs. Some of the observed time profiles can be due to superposition of bursts caused by ordered electron beams ejected with a constant time delay at the base of the corona.

Key words: Sun–Type III bursts—time profiles

1. Introduction

The time structure of Type III radio bursts was investigated in detail by several authors. These bursts are believed to be caused by electron streams moving outwards through the corona and exciting plasma waves which are transformed into electromagnetic waves. The usual time profile of a Type III burst is characterized by a sharp rise followed by an exponential type of decay. If the decay is due to collisional damping then one can calculate the kinetic temperature of the corona where the bursts originate. It was pointed out by Aubier and Boischot (1972) that it is possible to estimate the duration of the exciter (the time taken for the electron streams to cross a particular plasma level) and the decay constant from the observed time profiles. They also showed that the exciter duration and decay constants are positively correlated and questioned the collisional damping hypothesis. During the course of our observations of storm Type III bursts, we found that the time profile of these bursts can take a variety of forms of which three distinct profiles are presented here. They are (1) profiles where the intensity rises to a small but steady value before the onset of the main burst, (2) the intensity of the main burst reduces to a finite level and remains steady before it decays to the base level, (3) the steady state is present during the rise as well as the decay phase of the main burst.

2. Equipment and observations

2.1 *Equipment*

The observations were made with the Gauribidanur radio telescope (latitude 13° 36′ 12″ N and longitude 77° 26′ 07″ E). We have used the NS array of the telescope in conjunction with a multi-channel receiver. The effective area of the NS array exceeds 10,000 m^2. The central frequency of the receiving system is 34·5 MHz. The pre-detection bandwidth and the post-detection time constants were 15 KHz and 10 ms respectively. The separation between channels is 50 KHz and the present number of channels is sixteen covering a total bandwidth of 800 KHz. The minimum detectable flux with the above parameters is about 1 solar flux unit (SFU). The data are recorded in analog form using oscillographic recorders and also digitally on magnetic tape units. The equipment was operated for about an hour around the local noon during periods of enhanced emission from the sun.

2.2 *Observations*

We have already reported some of our observations on storm bursts which are mainly Of short duration (≈ 1s)and narrow band (Sastry 1969, 1971, 1972, 1973). In the present study we have considered time profiles of bursts whose total duration lies between 10–20 s. It is well known that the decametric noise storms consist of a succession of many Type III bursts. The duration of a Type IΠ burst at frequencies around 30 MHz lies in the above range (*e.g.* Krishan, Subramanian and Sastry 1980; Subramanian, Krishan and Sastry 1981). The frequency drift of a Type III burst at these frequencies is of the order of 30 MHz s^{-1}. Since the duration is in the expected range and also there is no measurable frequency drift in our records we believe that the events we discuss here are Type III bursts. Also, all the other types of known solar bursts have completely different characteristics in this frequency range.

Fig. 1 shows typical examples of bursts which were studied. In Fig. la, one can see that the intensity rises to about 20 per cent of the level of the main peak and remains reasonably steady for a period of about 4 s before the onset of the main burst, and we designate this as Type A profile. Another type of burst in which the intensity decays to about 30 per cent of the main peak level and remains steady for a period of 2 s before it decays to the base level is shown in Fig. lb, and is designated as Type B profile. In Fig. lc, there is a small but steady rise in intensity for a period of 3 s before the onset of the main burst, and also the main burst decays to a constant level of about 20 per cent of the main peak and remains steady for a period of 3 s, which we call a Type C profile. Out of the total number of 165 bursts studied, 34 per cent belong to Type A, 45 per cent to Type B and 21 per cent to Type C profiles. We have

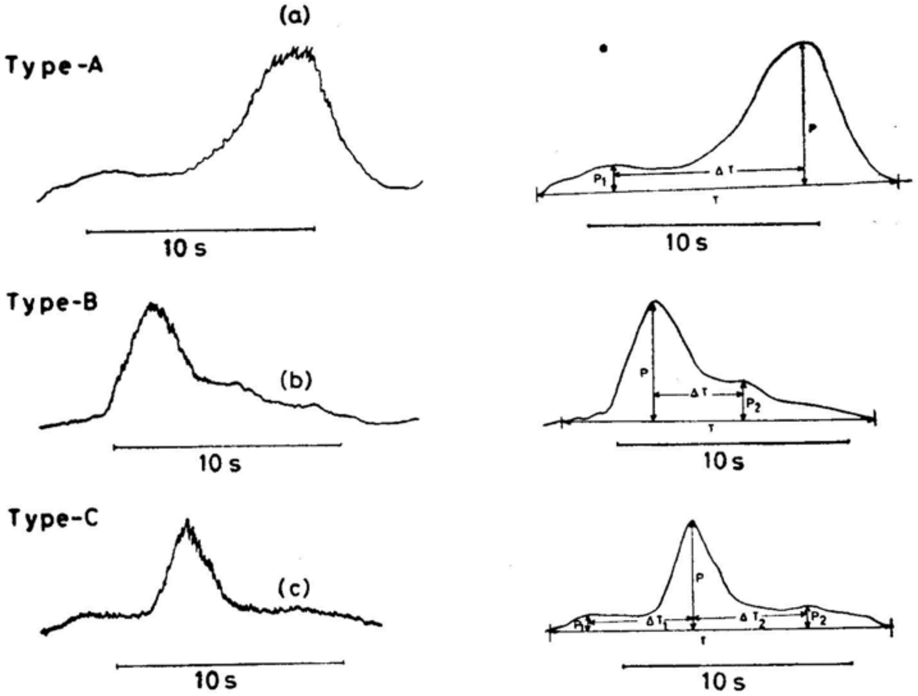

Figure 1. Typical examples of Type III burst profiles and the definition of burst parameters.

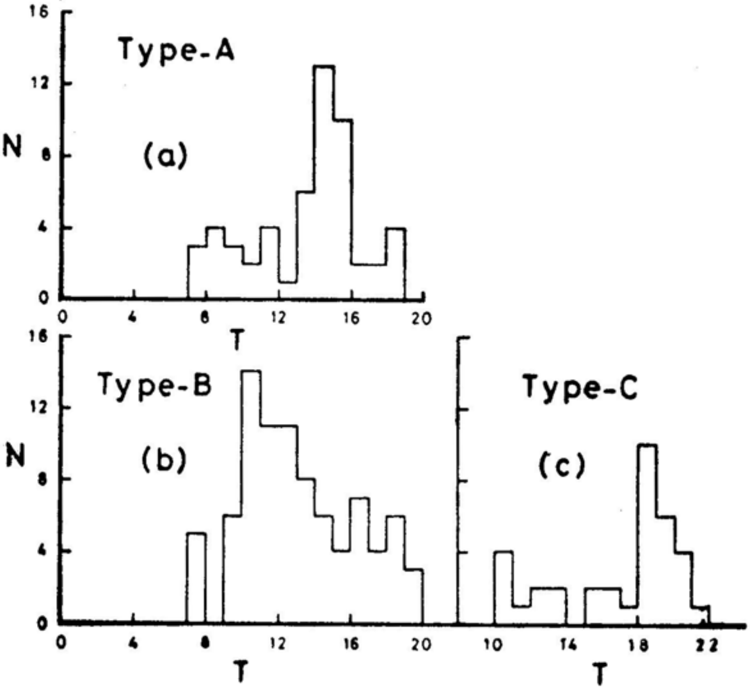

Figure 2. Histograms showing the number of bursts (*N*) versus total duration (*T*).

measured the various characteristics of these bursts illustrated in Fig. 1, which are of interest to us in the following discussion.

Histograms depicting the variation of the number of bursts versus duration are given in Fig. 2 for the three types of profiles. It can be seen that in the case of Type A profiles the duration lies in the range 14–16 s and that for Type B lies in the range 10–15 s. The duration of Type C profiles is larger (≥18 s).

In Fig. 3 the distribution of ΔT,the time interval between the peak of the main burst and the onset time of steady level in the case of Type A and the start of decay of the steady level in the case of Type B is shown. For Type A profiles, ΔT is about 5–6 s, whereas it lies between 3–6 s for Type B profiles. In the case of Type C profiles, ΔT_1 (interval between the main peak and the onset of steady level) ranges from 5–7 s and ΔT_2 (time interval between the main peak and the start of decay of the steady level) is ≤ 8 s.

The distribution of the following amplitude ratios are shown in Fig. 4: (1) the level of the pre-rise to that of the main peak P_1/P, (2) the level to which the main burst

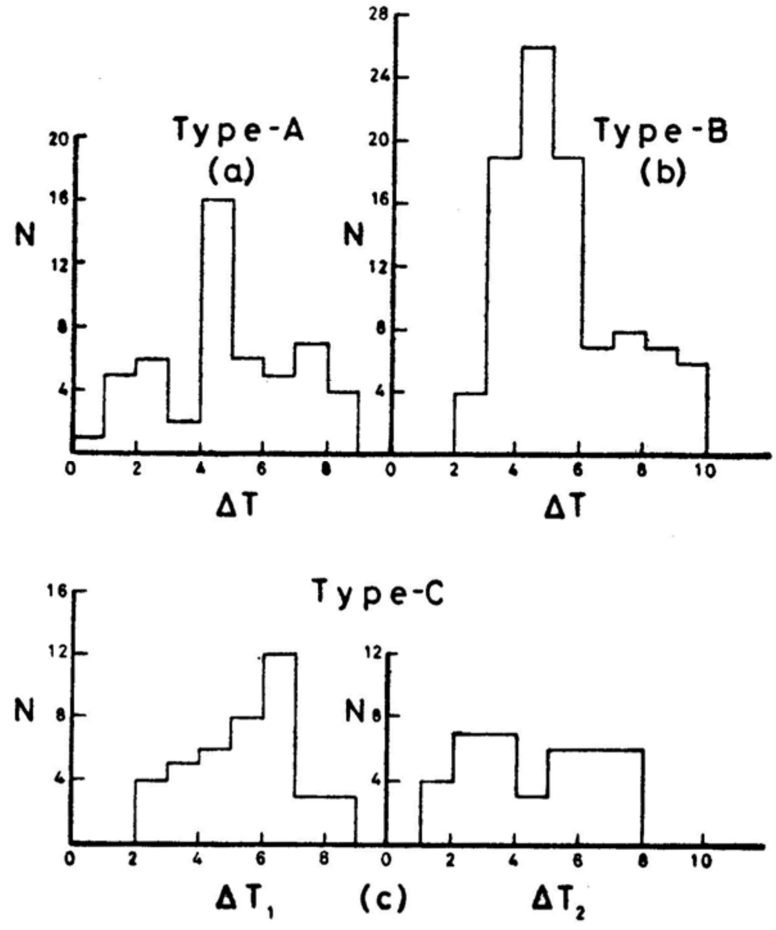

Figure 3 Histogarms showing the distributions of time intervals (ΔT). See Fig. 1 for the defintion of ΔT_1 and ΔT_2 in Type C profiles.

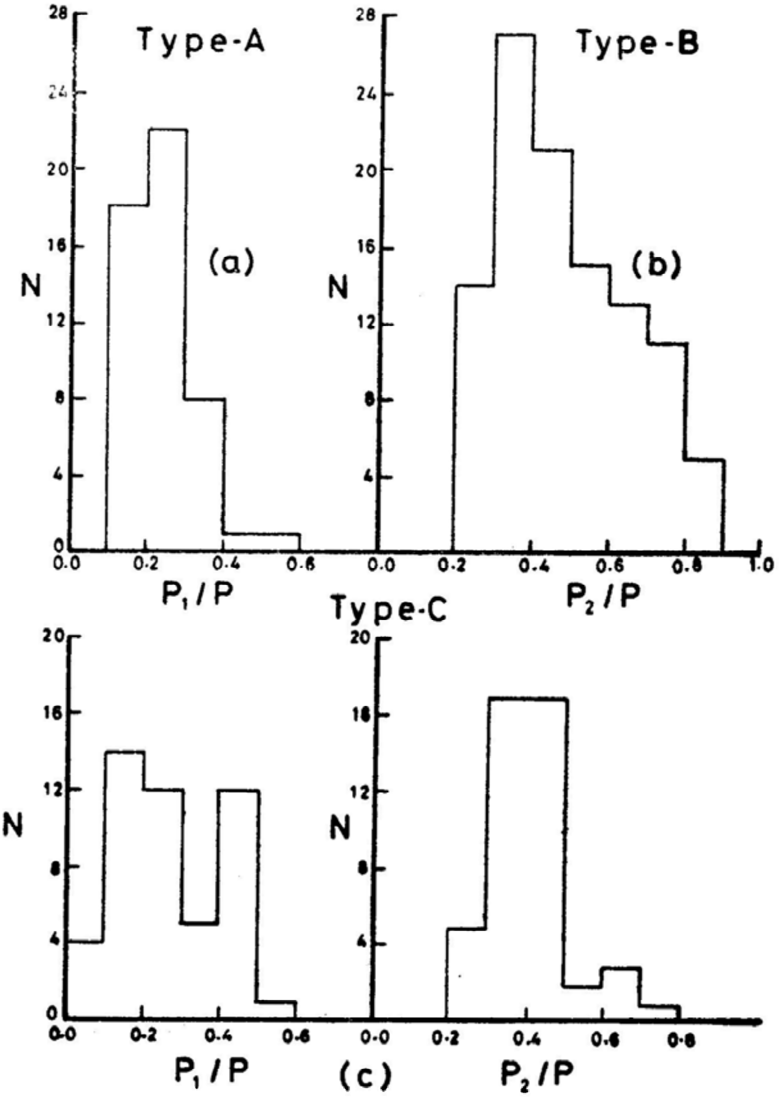

Figure 4. Histograms depicting the distribution of amplitude ratios P_1/P and P_2/P.

decays and remains steady to the level of the main peak P_2/P. It can be seen that the ratios P_1/P and P_2/P lie in the range 0·1 to 0·3 in all the profiles.

Following the procedure of Aubier and Boischot (1972) we have measured the decay constants of the main burst (τ_1)and also that of the final decay of the steady level (τ_2). Note that in the case of Type A profiles only τ_1 is present. From the histograms given in Fig. 5 it can be seen that the decay constants τ_1 and τ_2 lie in the range 1–4 s for all the three types of profiles. We did not find any strong correlation between the decay constant τ_1 and the duration of the exciter. Also τ_1 and the total duration T are uncorrelated.

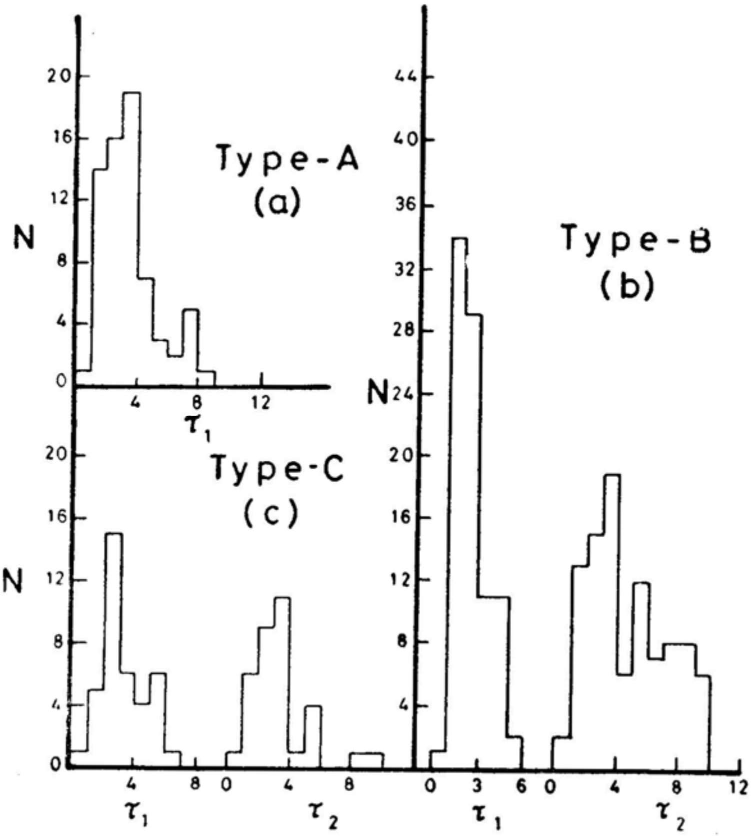

Figure 5. Histograms showing the distribution of decay constants τ_1 and τ_2.

3. Discussion

During the periods of enhanced emission at decametre wavelengths we have observed that there can be single or groups of bursts occurring at random intervals. Therefore, the simplest possible explanation for the three types of profiles presented here can be that they are due to superposition of bursts occurring randomly in time. But it is found that the occurrence of the three types of profiles presented here is maximum only on particular days although the period of enhanced emission may last for a much longer time. The fact that the time interval, ΔT as defined above tends to lie in a rather narrow range irrespective of the total duration of the burst, indicates that the profiles are not produced by entirely random superposition of independent events. Also the measured ratio of the amplitudes shows that the amplitudes of the initial and final phases are always a fraction of the main peak, and this ratio lies between 0·1–0·3. This need not be the case in case of bursts of various amplitudes occurring randomly In time.

The second possibility is that these profiles are the manifestations of fundamental-harmonic(f-h)pairs. From the work of Daigne and Møller-Pedersen (1974) and Rosenberg (1975), it is clear that the time separation between the peaks of the fundamental and harmonic emissions is, in general, constant and is equal to about 4 s. It was also found that the amplitudes in f-h pairs are comparable (Rosenberg 1975). In the present case it is difficult to rule out the f-h pair hypothesis on the basis of the time intervals ΔT which are about the same as found by above authors. But the fact that the intensity ratios P_1/P and P_2/P observed by us are much less than unity does not lend support to this hypothesis. Also, according to Caroubalos, Poquerusse and Steinberg (1974) the ratio τ_F/τ_H of the decay constants of the fundamental and harmonic should be of the order of two if one assumes that the intensity of the fundamental $I_F \propto W$ (the energy density of plasma waves), the intensity of the harmonic $I_H \propto W^2$ and the temperatures in the regions of both fundamental and harmonic emissions are the same. Our observations show that τ_1 and τ_2 are in general same and in some cases τ_2 can be greater than τ_2 Even if our Type A and Type B profiles are possible manifestations of f-h pairs, it is difficult to interpret Type C profile on this basis. In the case of f-h pairs studied by Caroubalos, Poquerusse and Steinberg there are two clear-cut peaks in emission whereas in the profiles presented here no prominent subsidiary peak exists. Therefore, we believe that the profiles are probably not due to fundamental and harmonic emission. Zaitsev, Mityakov and Rapo port (1972) have calculated the Type III burst profiles by solving the one-dimensional relativistic quasi-linear equations on a timescale $t \gg \tau$ where τ is the characteristic time for the development of two-stream instability (time taken for the plateau formation $= \omega_{Pe}\, n/n_s$ where ω_{P_e} is the plasma frequency,*tnt*is the density of the background plasma and n_s is the density of electrons in the stream) and for the spatial scales $x \gg L$ where L is the initial thickness of the cloud under the initial conditions of a local explosion type. They have shown that at decametre and longer wavelengths—where the characteristic time of the absorption associated with collisions of electrons with ions in a 'cold' plasma, ν_{eff}^{-1} is much greater than the characteristic time of absorption due to Landau damping in the back of the stream $\Delta x/V_s$ (where Δx and V_s are the extent of the stream in the corona and its mean speed respectively) is satisfied—collisions can be neglected and only Landau damping in the tail of the stream determines the dissipation of plasma wave energy. Their theoretical profiles agree well with the experimental data in the hectometre range under the assumption that electromagnetic wave generation takes place at the second harmonic of the plasma frequency. Zaitsev *et al.* (1974) extended the same in the case where the injection time of hot electrons from the region of the flare is considerably greater than the time of existence of the burst at a given fixed frequency. The dissipation mechanism is the same Landau damping on tail of the beam even at the decametre and metre wavelengths. The results of Zaitsev *et al.* (1974) have been confirmed by the extensive numerical work done by many authors (Takakura and Shibahashi 1976; Magelssen and Smith 1977; Grognard 1980). The energy density of plasma waves is given by

$$W_L(\xi) = \frac{n_s\, \epsilon_0}{3\sqrt{2\pi}} \frac{(\epsilon_0/m)^{1/2}}{\nu_{\text{eff}}\, x} \left(\frac{2m\,\xi^2}{\epsilon_0}\right)^3 \exp\left(\frac{-2m\,\xi^2}{\epsilon_0}\right)$$

for the initial momentum distribution of the stream

$$f_0(p) = p\, \frac{n_s}{(2\pi m\epsilon_0)^{1/2}} \exp(-p^2/2m\epsilon_0).$$

The mean velocity of the beam

$$V_s = (\epsilon_0/m)^{1/2}$$

where n_s is the electron density in the beam, ε_0 is the initial energy of the beam, $\xi = x/t$, x is the distance between the photosphere and the respective plasma layer, m is the mass of an electron and v_{eff} is the effective number of collisions.
The energy density reaches its maximum when

$$t = t_{\max} = x\left(\frac{3}{2}\frac{\epsilon_0}{m}\right)^{-1/2}.$$

It is possible that the profiles presented here are due to the superposition of two or three bursts caused by ordered electron beams ejected with a constant time difference. In the case of Type A profiles, the electron beam responsible for the main burst should reach the appropriate plasma level soon after the electron beam causing the pre-rise leaves the same level. Then the time interval 'ΔT' is equal to the time at which W_L (plasma wave energy density) causing the main burst reaches its maximum. Since we know ΔT from observations, we can find the initial energy of the beam causing the main burst. From the observed ratio P_1/P, we can find the initial energy of the first beam. If we take $x = 1{\cdot}1 \times 10^{11}$ cm and $\Delta T = 4$ s, then $V_2 = 1{\cdot}856 \times 10^{10}$ cm s^{-1} and $V_1 = 0{\cdot}37 \times 10^{10}$ cm s^{-1}, where V_1 and V_2 are the mean velocities of the first and second beams respectively. By computing the resultant time profile with the above initial energies of the beams, we are able to reproduce approximate profiles of Type A and the rise part of Type C. It is not possible to reproduce the steady decay of Type B and Type C profiles in this manner. Note that the superposition of W_L is possible since we have used a combination of two beams which follow independent paths. It may be possible to construct all the time profiles by a combination of more than two beams. But it is not clear how the electron beams are accelerated to the above energies and ejected with constant time difference.

The other possible explanation for the observed profiles is that the conversion mechanism of plasma waves into electromagnetic waves and their decay show such a peculiar character.

4. Conclusion

We have investigated three distinct time profiles of Type III bursts occurring during the periods of enhanced emission. These are: (1) profiles where the intensity rises to a small but steady value before the onset of the main burst, (2) the intensity of the main burst reduces to a finite level and remains steady before it decays to the base level, and (3) the steady state is present during the rise as well as the decay phase of the main burst.

It was shown that these profiles are not due to random superposition of bursts with varying amplitudes. They are also probably not manifestations of f-h pairs. Some of the observed time profiles can be due to superposition of bursts caused by ordered electron beams ejected with a constant time delay at the base of the corona.

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