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Pulsating Radio Emission at Decametre Wavelengths from the Sun

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Abstract. Observations on the pulsation pattern in the time profile of short duration solar radio bursts at decametre wavelengths are presented. The pulsations are found to be present predominantly in the saturation phase of the burst. A tentative physical model based on the non-linear development of the waves interacting in a turbulent medium is invoked to explain the origin of the pulsations.

Key words: explosive instability—pulsating burst

1. Introduction

The periodical temporal variations in the intensity of solar radio emission have been reported by several workers, *e.g.* Rosenberg (1970), Mclean *et al.* (1971), Abrami (1972) and Tapping (1978). Most of these observations were made at wavelengths of approximately 2 m and less. These pulsations occurred during some phases of type IV events. These are broad band and are seen at all phases *i.e.* growth, plateau and decay of that burst. Santin (1971) reported his observations on quasi-oscillatory decay in type III radio bursts. In the decametre wavelength range, we have already reported some observations on quasi-periodic variations of enhanced background emission during intense noise storms (Sastry 1969). Achong (1974) observed similar pulsation of the enhanced continuum in the frequency range of 24–26 MHz. In this paper, we report our observations on a different type of pulsation pattern in the intensity time profile of short duration radio bursts at decametre wavelengths. A tentative physical model to explain the observed characteristics is proposed.

2. Equipment

These observations were made with the N-S arm of the Gauribidanur decametre wave radio telescope. This radio telescope is a Mill's ' T ' type array operating in the frequency range 25 to 35 MHz. The N-S array of the radio telescope has a collecting area of approximately 15,000 m^2 and beam-widths of 15°and 0·5° in the E-W and N-S directions respectively. The receiving system consists of eight channels with centre frequencies around 34·5 MHz. The separation between channels is 50 kHz and the bandwidth of each channel is 15 kHz. The time constant used is 20 milliseconds.

3. Observations

We observed the Sun each day for about an hour centred at local noon during storm periods. Since the sensitivity of the system is very high a large number of new and peculiar bursts hither to unclassified were detected. On several occasions we recorded a burst in which there is a smooth growth of intensity to a maximum in a short time and during the maximum phase the intensity exhibits quasiperiodic pulsations and then decays with the same smoothness. The basic distinct feature of these profiles is the presence of oscillations or pulsations during the saturation phase of the radio emission. Typical examples are shown in Figs 1a, b and c. In Fig. 1a one can see a rise in the intensity starting around $06^h\ 51^m\ 58^s$ UT and then going into oscillations with an approximate period of 2 seconds. After three oscillations the intensity decays to the preburst level. The total duration of the burst is about 6 seconds. A similar burst is shown in Fig. 1b starting around $06^h\ 29^m\ 41^s$ UT. Here the total duration and the period of oscillation are larger *i.e.* 10 and 3 s respectively. Another burst with twice the number of oscillations is shown in Fig. 1c. The total number of events recorded during the period April–July 1980 is 22. As pointed out here, all these bursts occurred during periods of intense noise storms where the base level of emission is already very high.

We have derived several characteristics of these bursts from the observed time and frequency profiles. The various measured parameters of the burst are illustrated in Fig. 2. Fig. 3a shows a histogram of the number of bursts versus the pulse repetition rate. It can be seen that the most common value of the pulse repetition period lies between 2 and 5 seconds. A histogram of the number of bursts versus total durations is given in Fig. 3b and it is clear that the total duration, τ, ranges from 5 to 15 seconds. A modulation index m defined as

$$m = \frac{\Delta I}{2I - \Delta I},$$

is calculated for each burst. From the histogram of Fig. 3c it can be seen that the value of m lies between 0·2 and 0·4 in a majority of cases. We have also looked for correlations between the various parameters of the bursts. Fig. 4 is a scatter plot of the average peak intensity $\langle I \rangle$, and the average pulse amplitude, $\langle \Delta I \rangle$. It is obvious that these two parameters are positively correlated and the linear correlation coefficient is found to be +0·7. A plot of $\langle I \rangle$ versus the pulse repetition period, $\langle \Delta\tau \rangle$ showed no significant correlation. A similar result is obtained for correlation between the pulse amplitude, $\langle \Delta I \rangle$, and the pulse repetition period, $\langle \Delta\tau \rangle$. No correlation is also found between the modulation index, m, and the pulse repetition period, $\langle \Delta\tau \rangle$. The average individual pulse profile is found to be

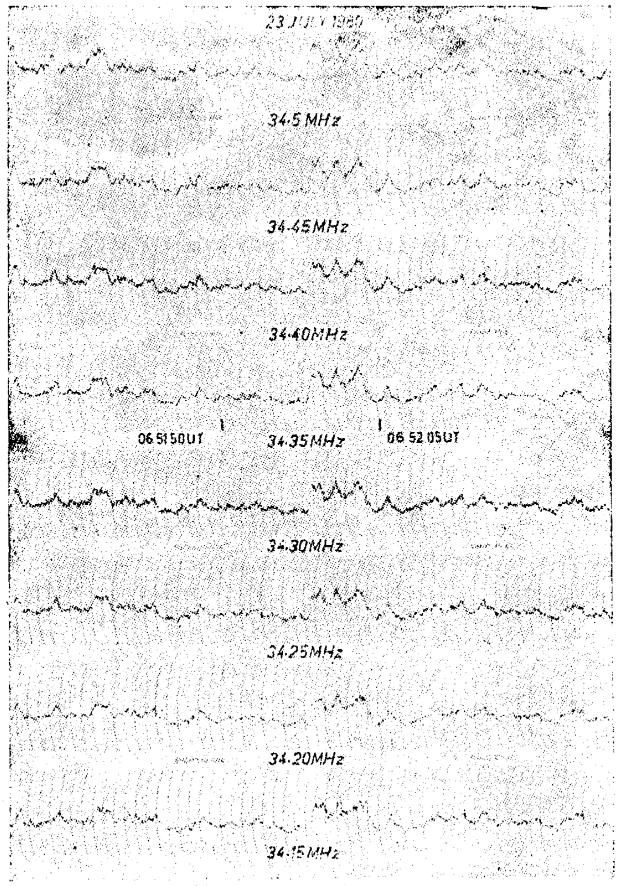

Figure 1a. Examples of the time profiles of pulsating radio bursts. The ordinate is the receiver output voltage (1980 July 23).

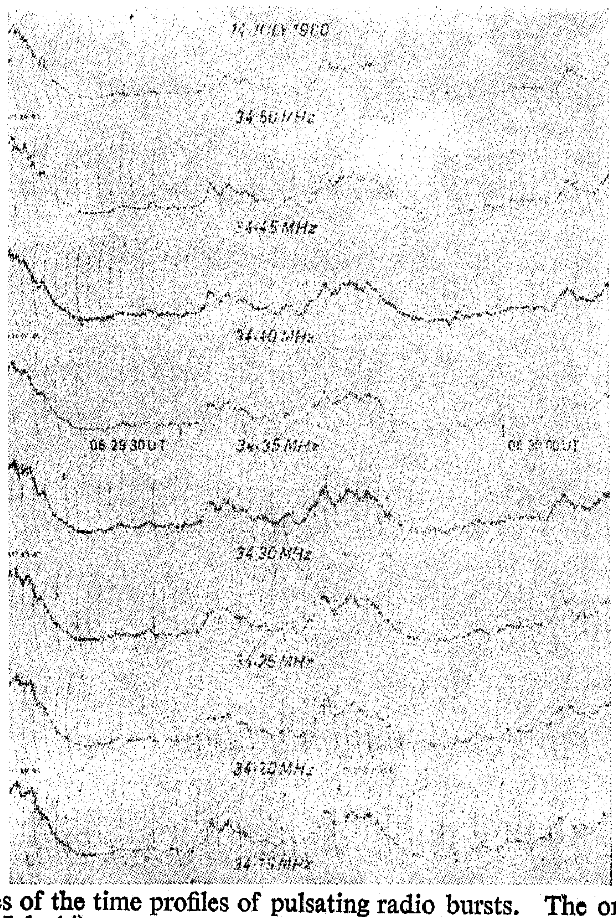

Figure 1b. Examples of the time profiles of pulsating radio bursts. The ordinate is the receiver output voltage (1980 July 14).

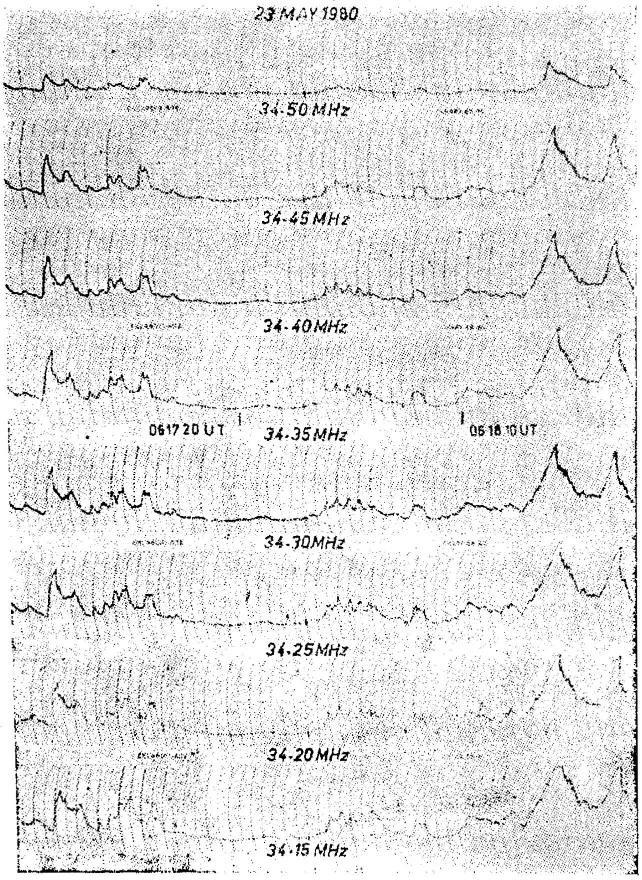

Figure 1c. Examples of the time profiles of pulsating radio bursts. The ordinate is the receiver output voltage (1980 May 23).

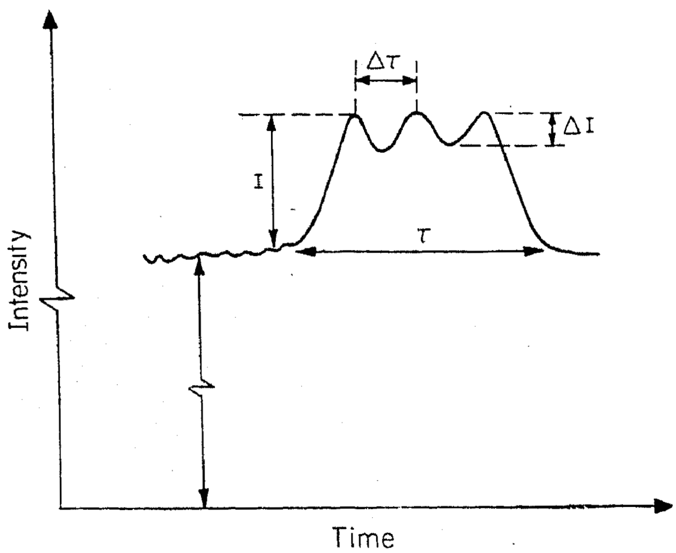

Figure 2. Explanation of the burst parameters.

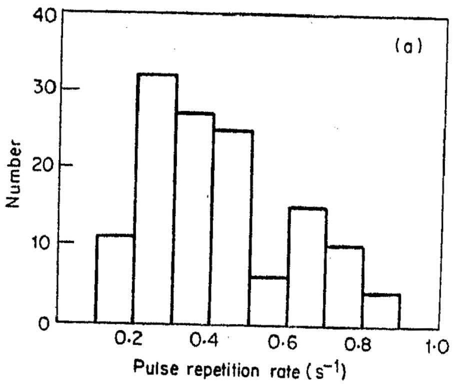

Figure 3a. Histogram of the number of bursts versus the pulse repetition rate.

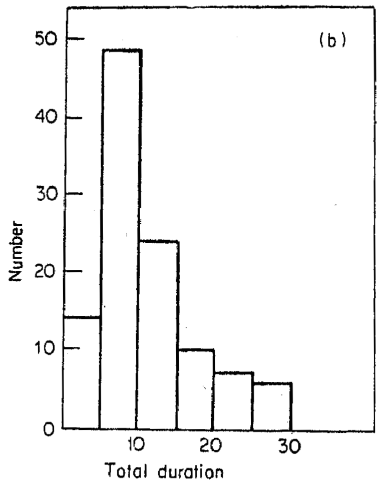

Figure 3b. Histogram of the number of bursts versus the total duration.

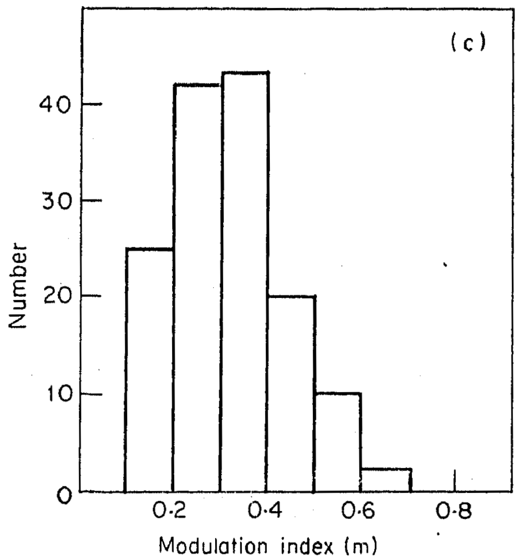

Figure 3c. Histogram of the number of bursts versus the modulation index.

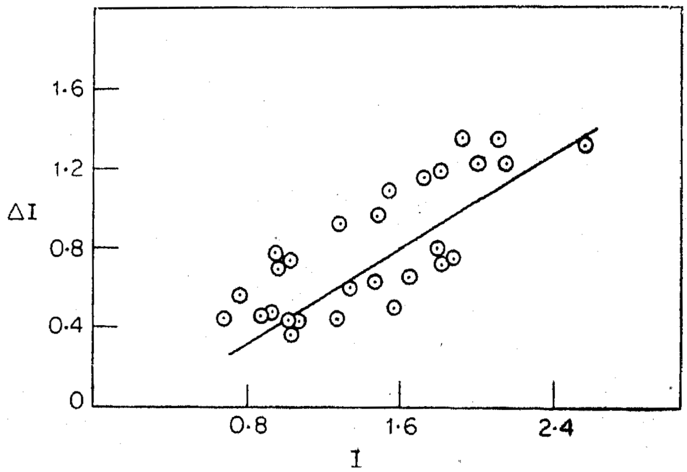

Figure 4. A plot between the average peak intensity $\langle I \rangle$ and the average pulse amplitude $\langle \Delta I \rangle$ shows a strong correlation between $\langle I \rangle$ and $\langle \Delta I \rangle$.

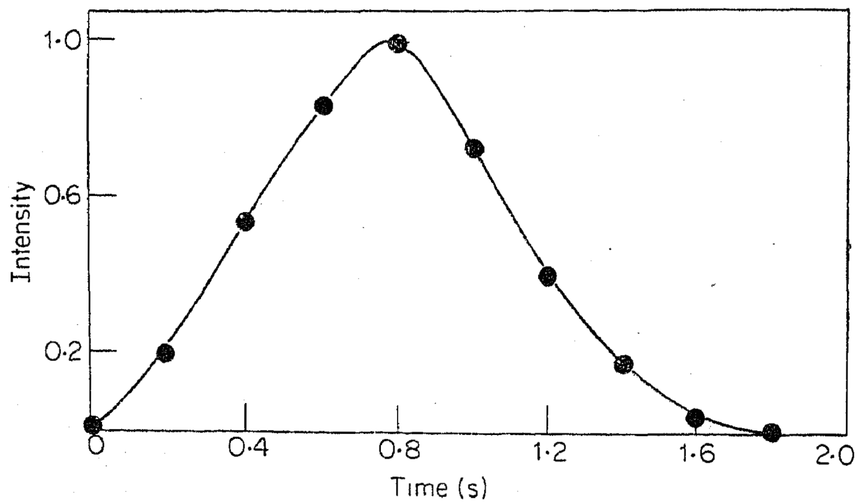

Figure 5. The average time profile of a pulse.

symmetric (Fig. 5). These results do not agree with those obtained by Tapping (1978) and McLean and Sheridan (1973).

In conclusion, one can identify these bursts by the following distinct characteristics.

1. The pulsations are seen only in the saturation phase of the burst.
2. The pulse repetition period lies within 2–5 seconds.
3. The amplitude of the individual pulse remains approximately constant during the pulsating phase.

4. Discussion

Rosenberg (1970) and McLean *et al.* (1971) proposed that the modulated radio emission was due to synchrotron emission in a magnetic flux tube and the pulsations are introduced due to the radial oscillations of the flux tube. Abrami (1972) noticed that the above model fails to account for the arrest of emission increase accompanying the start of pulsations.

We have sought a physical model where the oscillations can set in only during the saturation phase of the burst since this is a distinct feature of the bursts we observed. The basic system responsible for these modulated bursts is an electron beam-plasma system. This system has been shown to support positive as well as negative energy waves. The coupling of the positive and negative energy waves gives rise to an explosive instability where the amplitude can become infinite in a finite interval of time, although due to various non-linear effects mentioned below, the growth of the amplitude will be arrested. The initial growing phase of the observed burst can be attributed to this explosive instability. The excitation of the explosive instability is a threshold effect. Since the background level of emission over which the burst is superimposed is very high, the conditions for the explosive interaction of the waves are satisfied. The time of explosion is a function of the initial amplitudes of the interacting waves. The saturation of the explosive instability is due to the non-linear complex amplitude-dependent frequency shift caused by three wave coupling.

Further the non-linear frequency shifts combined with the linear dissipation effects set the saturation stage into an oscillatory mode. It can be shown that the time period of pulsations is a function of the level of the initial enhanced background and not the peak intensity I. This would explain the absence of correlation between the pulse repetition rate $(\Delta\tau)^{-1}$ and $\langle I \rangle$, $\langle \Delta\tau \rangle$ and pulse amplitude $\langle \Delta I \rangle$ and therefore $\langle \Delta\tau \rangle$ and the modulation index m. The significant correlation observed between the average pulse amplitude $\langle \Delta I \rangle$ and the average peak intensity $\langle I \rangle$ is a natural consequence of this mechanism since the pulsations come into play only when I attains a certain value at which the non-linear effects become predominant. The solution of the non-linear wave equations including three wave coupling is given with and without linear dissipation by Oraevskii *et al.* (1973), Weiland and Wilhelmsson (1973) and Weiland Wilhelmsson (1977). The time period of the pulsations has been determined in Fukai, Krishan and Harris (1971). The theoretical results of the above investigations predict the pulsations to continue throughout the decay phase unlike our observations, where the decay phase is almost pulsation free. This last stage of the burst could be a consequence of the passage of the electron beam out of the interaction region. The decay of the remaining field could then be due to collisional or collisionless processes.

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