INVESTIGATION OF THE LONGITUDINAL STRUCTURE OF THE INTERPULSE EMISSION OF PSR 1133+16 AT 25 MHz RANGE

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Introduction

Observations of PSR 1133+16 at frequencies of 20 and 25 MHz were conducted for the first time nearly 20 years ago (Bruck and Ustimenko 1973), and during the course of this work, its interpulse emission (IPE) was discovered. Systematic investigations of this pulsar at frequencies of 17, 20 and 25 MHz have been conducted using the UTR-2 radio telescope over the interval between 1972 and 1988, and occasional additional studies at 30 and 40 MHz were carried out since 1981 using DKR-1000 radio telescope. The form of the main pulse was studied and IPE searched for and investigated. The sporadic IPE components were identified on the basis of their intensity, their dispersion measure, and their time and frequency repeatability, and in some cases were confirmed by observations at different observatories. Intense IPE was found at all of the frequencies; however, after long integration its average intensity decreases—in some cases—below the noise level (Ustimenko 1983). These observations had yet to be objectively analyzed and explained; therefore some special investigations were conducted between 1979 and 1988. Some of these results are presented in other papers at this conference and in Bruck (1987). A complete presentation of these studies will be published in a forthcoming paper.

In this paper we shall consider the effect of integration on the observed structure of the IPE and estimate its form, duration, appearance probability, and integral intensity. The main features of the IPE usually manifest themselves in single, long (1 to 2 hours) observations.

The UTR-2 investigations were conducted by tracking the pulsar for more than two hours in 24 separate channels either in the 25-MHz band or simultaneously in the two bands: 25 and 20 MHz, or 25 and 17 MHz. The time and frequency resolutions were 25-50 ms and 1.5-14 kHz, respectively. Each day of observation resulted in a total of 20 realizations in 24 channels—that is, nearly 500 independent measurements, each representing a synchronous average of 100-200 pulses.

The main-pulse. IPE modes

The main pulse in figure 1 was obtained by averaging 5400 pulses over a 135-kHz band with a resolution of 24 or 48 ms. Its characteristics are as follows: the half-width is 95 ms, the width at zero level 160 ms, the distance between the components 48 ms, and the intensity ratio 1:1.3. The main pulse properties at 20 MHz change little, and all these agree rather well with the observations at higher frequencies (Bruck 1987, Bruck and Ustimenko 1978).

An algorithm for self-consistent classification of the coefficients of cross-correlation functions (CCF) was developed both to identify the IPE and investigate its structure. In order to exclude main pulse effects on the algorithm, it was limited to a single realization (378 CCFs), each of which was the sum of 200 pulses over a 135-kHz band. As a result, three classes of modes (1, 2, and 3) were formed which are shown in figure 1. Within the class the CCF is +0.7, between the classes it is either 0 (1-2 and 2-3) or −0.5 (1-2). Average profiles of the IPE modes have signal-to-noise ratios ≥ 8 and IPE features are found with up to 30% of the main pulse amplitude and 100% of its average flux. The extent of the IPE regions is greater than 200° in longitude, and the maximum-intensity regions are concentrated near the main pulse and 180° away from it; hence IPE is observed throughout the profile. When comparing the average profiles of the different modes with the longitudinal dependence of the number of samples above the level of 2.75 σ (see figure 1.6), it follows that they essentially correspond to each other. The main pulse region and at least three other regions of intensive IPE generation are reliably defined with this method. The two IPE regions close to the main pulse (+60° and −60° from its center) are possibly connected with the same pole. The third region, near the center, is perhaps connected with the second pole. The radiation minima are located as well—for instance, at a longitude of about −120°. The presence of these stable minima plays a decisive role in identifying IPE and correctly determining its intensity. By the way, note that the statistical-processing method for a signal-to-noise ratio > 1 is often simpler and more reliable for discovering and investigating the IPE fine structure. Finally another remarkable feature

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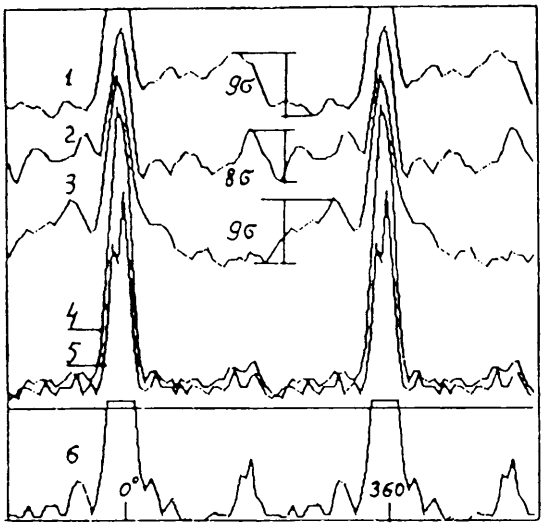

Figure 1 PSR 1133+16 at 25 MHz. 16 × 8 kHz channels, total bandwidth is 135 kHz, 5400 pulses with 50 points per period. The resolution is 48 ms for traces 1–4 and 6, and 24 ms for trace 5. Traces 1–3 show modes of IPE, 4 and 5 are the mean signal, and 6 is the number in excess of a 2.75σ threshold. The horizontal line is the zero level for traces 4 and 5.

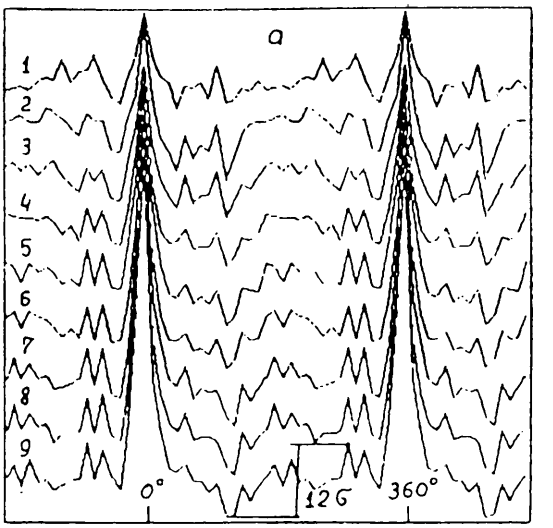

Figure 2a PSR 1133+16 at 25 MHz. 16 × 8 kHz channels, total bandwidth is 128 kHz, 80400 pulses with 32 points per period. Cumulative average profiles are shown with 9000-pulse increments. Maximum S/N for the main pulse is 48, and 12 for the IPE.

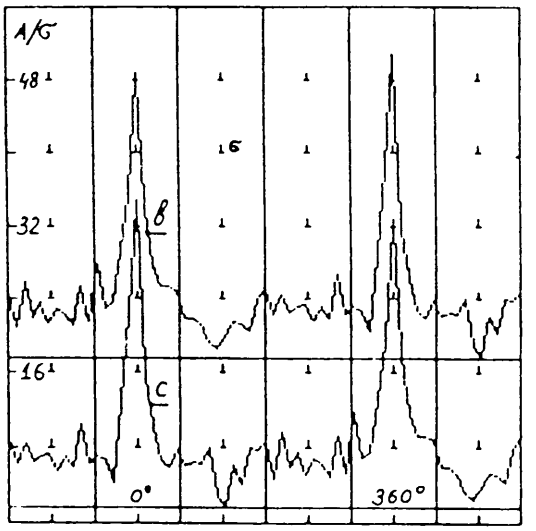

Figure 2b–c PSR 1133+16 at 25 MHz, 80400 pulses with 128-kHz bandwidth. The horizontal lines show the zero level. The vertical scale is in S/N units.

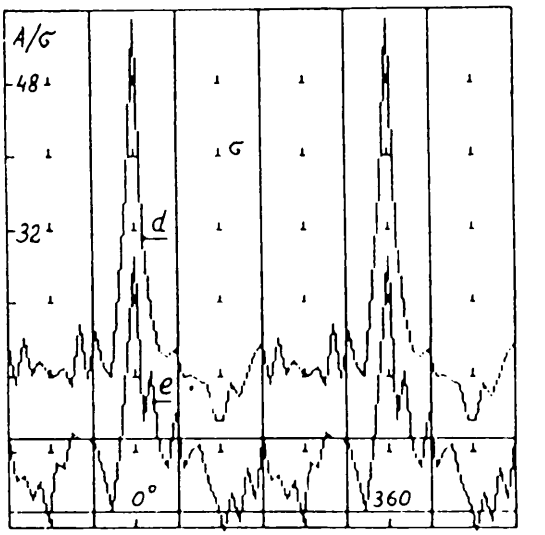

Figure 2d–e PSR 1133+16 at 25 MHz, the most intense 4000 pulses.

of the IPE is seen in figures 1.4 and 1.5. The sum of the 1, 2 and 3 modes without accounting for the constant component shows an absence of the IPE over 2σ (= 3% of the main pulse) in accordance with the results in Ustimenko (1983) and Phillips and Wolszczan (1989). The summation of all the realizations yields the lower IPE level. At the same time a correct drawing of the zero line using the maximum statistics method (Bruck and Ustimenko 1978) or even simply using the middle level outside of the IPE regions in figures 1.1, 1.2 and 1.3 gives the average flux of the IPE greater than 100% of the main pulse.

The average flux of the IPE

Both the dependence of the intensity and appearance probability of the IPE on longitude considered above were found to be rather complex, with the observed IPE minima not being absolute. Similar results are also obtained when analyzing other observations. The question arises as to the lifetime of the radio-frequency radiation features observed. In order to answer this question, 19 observation series of 50-hours duration were conducted over a three-month period. The total integration was 80400 pulses in the 128-kHz band at a resolution of 27 ms. Figure 2 shows: a) the signal-integration dynamics

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with time, b), c) and d) the average-signal profiles of 2 × 40000 and 80400 pulses, and e) the most intense signals (4000 pulses). Both the high cross-correlation between the independent observations (CCF = 0.94 in figure 2b and 2c) and the high signal-to-noise ratio enabled us reliably to identify and delineate a number of the IPE features discovered earlier. To reiterate, these are: the extended region at the back and front of the main pulse, the higher-intensity regions at +60° and 180°, the minimum-intensity region with the center at −120°, and the local minima at +30° and +120°. The region occupied by the IPE is about 360°. It represents an average flux of about 170% of the main pulse average flux and assumes maximum values of up to 30% of the main pulse with a signal-to-noise ratio of 10-12. These observations agree with those of Smirnova and Shabanova (1989) and permit a rough estimate of the spectral index of the IPE between 102 MHz and 25 MHz—that is, about −3.

Conclusions

It follows from the observations, in spite of their inevitable fragmentary character, and also from a review of all the observational material that

1. the frequency band of IPE seems to be smaller than that of the main pulse,

2. the main pulse forms at various frequencies differ slightly, and

3. IPE is observed at all longitudes. Therefore, a correct estimate of its intensity depends on the stability of the local minima positions, the method of estimating zero-line positions, the frequency band, and the integration time.

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