PULSAR MICROSTRUCTURE QUASI-PERIODICITY

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ABSTRACT

Microstructure in pulsars occasionally has a quasi-periodic character with an average period of around 0.9 ms. A survey of this little known phenomenon (time characteristics, polarization, frequency behaviour, etc.) together with some new results are presented. Some physical interpretations (e.g. vibration of the neutron star, polar cap periodical sparking, standing wave pattern in the velocity of light cylinder model) are also presented.

1. INTRODUCTION

Quasi-periodicity in pulsar radio frequency pulse microstructure is an occasional phenomenon at present known to exist in PSR 0329+54, 0809+74, 0834+06, 0950+08, 1133+16, 1508+55, 1919+21, 1944+17 and 2016+28. Quasi-periodicity was noted for the first time by Hankins (1971) who presents one PSR 0950+08 pulse with a clear quasi-periodic sequence. Detailed studies of the PSR 2016+28 quasi-periodicity were done by Boriakoff (1973, 1976) and by Cordes (1976). Additional work on these and other pulsars was done by Backer (1973), Cordes and Hankins (1977), Ferguson et al. (1976), Ferguson and Seiradakis (1978), Hankins and Boriakoff (1978), Kardashev et al. (1978), Hankins and Boriakoff (1980) and Boriakoff (1980).

2. MORPHOLOGY

Quasi-periodicities appear most conspicuously as a series of micropulses in sequence that have constant time separation, or have sudden phase steps (one of the time intervals between micropulses is different from the others) or have variable time intervals with both continuous variability and with random-like variability (Figure 1). A rough average for the time interval is 0.9 ms, and the micropulse width is usually less tnan half the micropulse separation. The sequences last

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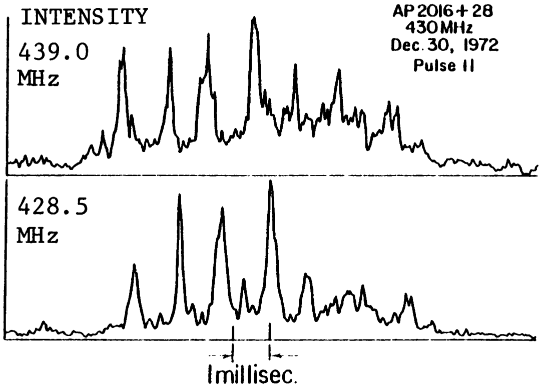
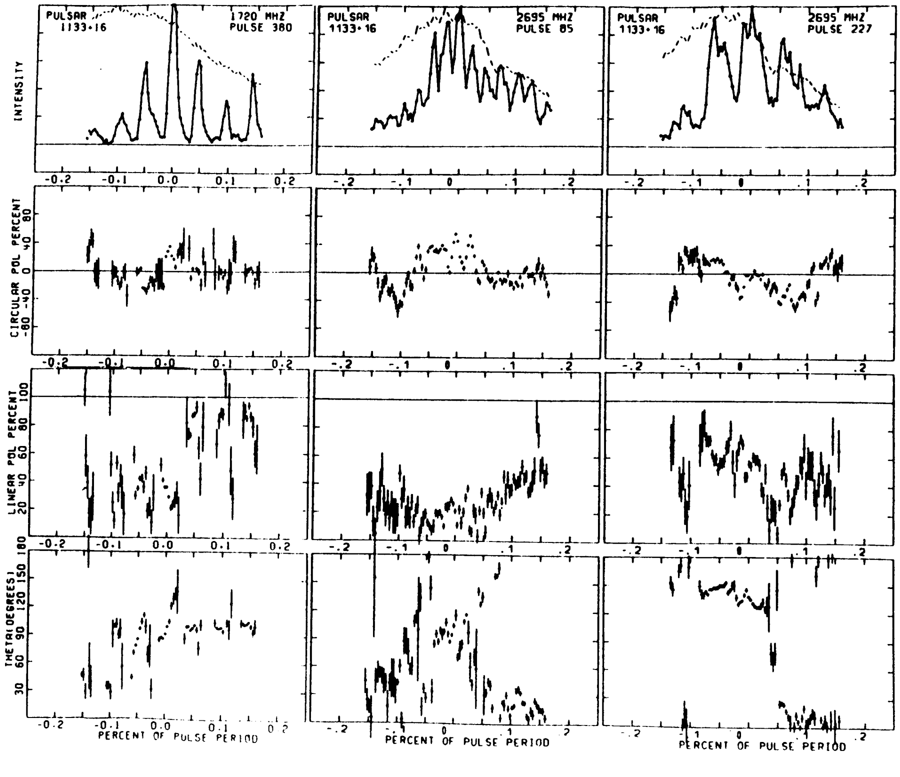
Figure 1.



from two-three micropulses up to 15-20 micropulses, and they appear within longitudes corresponding to the average pulse profile. A claim by Backer (1973) that micropulse sequences extend for more than one pulse period in PSR 2016+08 and that the quasi-periodicity remains in phase with the subpulses as they drift has been further investigated by Cordes (1976) with inconclusive results. Occasionally two or more quasi-periodicities can co-exist simultaneously (Figure 2, pulse 227,

Fig. 2.



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and also Kardashev et al. (1978)). Individual micropulses belonging to quasi-periodicities are similar to those that appear isolated, they have similar characteristic widths, etc. However, in one respect, they may be different; they seem to have intensities which are a function of the quasi-period. The quasi-periodic sequences sometimes appear alone and sometimes superimposed over subpulses or over other amorphous noise-like emission, but they do not seem to appear at pulse longitudes where other emission does not appear. The PSR 0950+08 interpulse has quasi-periodicities of similar type to those of the main pulse (Hankins and Boriakoff, 1980). In its main pulse low level quasi-periodic sequences are very common.

3. POLARIZATION

Cordes and Hankins (1977) examined the polarization of the microstructure of PSR 1133+16 and 2016+28 at 430 MHz. Based on average polarization parameter acf's they conclude that the polarization preferentially changes state at the edges of micropulses (and subpulses). This also applies to quasi-periodic micropulses, which appear very frequently in PSR 2016+28. Ferguson and Seiradakis (1978) examine PSR 1133+16 at $\nu \geqq 1420$ MHz and present individual pulses with quasi-periodic sequences. In some cases we see that the linear polarization angle remains constant inside some micropulses and in other cases a large angle change happens within the micropulse. In quasi-periodic sequences the angle of sequential micropulses can be constant, or can change within the micropulse but its average is the same as that of other micropulses in the sequence (Figure 2, pulse 380) or can have a smooth variation from micropulse to micropulse. That is, the polarization angle appears to continue rotating even when the micropulses are not there (Figure 2, pulse 85). Other types of variations have been observed as well. Other polarization characteristics are in general without obvious clear sequences.

4. RADIO FREQUENCY BEHAVIOUR OF QUASI-PERIODICITIES

Boriakoff (1980) has shown that in PSR 1133+16 the quasi-periodic sequences have the same micropulse time separations at 318 and 196.3 MHz. Our observations of PSR 0950+08 at 1406 - 430 MHz have shown quasi-periodicities where the micropulse time separation is the same at both frequencies (Figure 3). The same effect is seen in Figure 4; it shows a single pulse of PSR 0950+08 at 318 and 196.3 MHz (Boriakoff and Jackson, 1980) composed entirely of a quasi-periodic sequence, and its ccf. These and other single pulses are very strong evidence that the quasi-periodicities have the same period (time interval) at different radio frequencies in PSR 0950+08 and 1133+16. This seems to be a consequence of the wide bandwidth of micropulses (Boriakoff, 1980).

Figure 3.

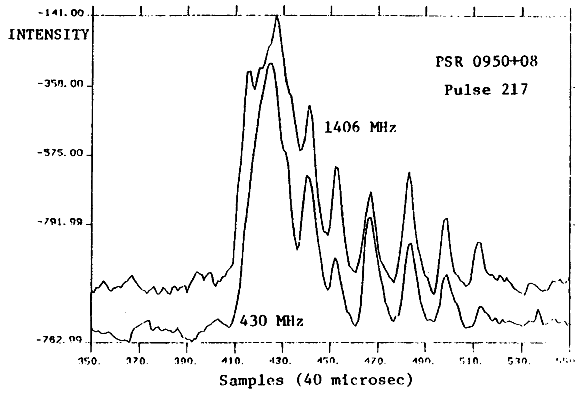
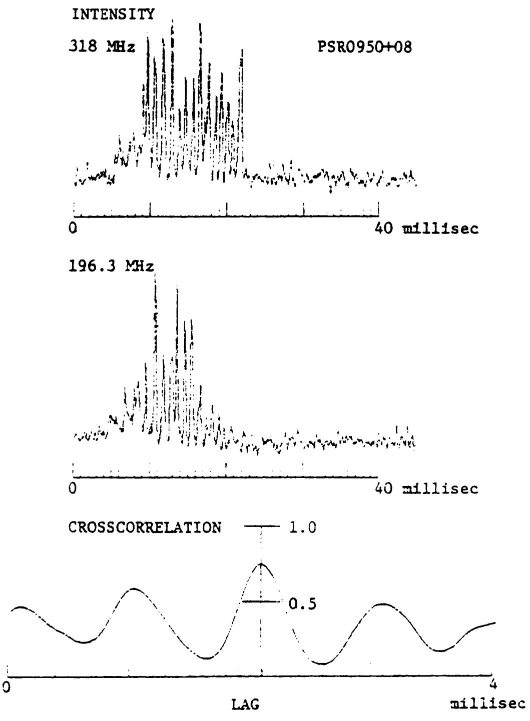


Figure 4.



5. PHYSICAL INTERPRETATIONS

Computations of vibration (oscillation) periods of neutron stars (e.g. in a series of papers by Thorne and others, references in Ipser and Thorne, 1973) have shown that radial and non-radial oscillations have periods of the order of 1 ms. Boriakoff (1973, 1976) has suggested that these oscillations are the cause of the quasi-periodicities. Van

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Horn (1980 and personal communication) has recomputed the periods for non-radial oscillations that have no damping due to gravitational radiation and has found that they have periods close to those of quasi-periodicities. An objection by Cordes (1976) stating that since the period varies from pulse to pulse and even from subpulse to subpulse the frequency is not stable enough to represent relatively high Q neutron star oscillations may be overcome by assuming closely spaced oscillation modes with mode beating, as is known to happen in white dwarfs. Indeed, period histograms indicate that many frequencies are present. Van Horn also proposes that other lower frequency oscillations are the basis for the drifting subpulses.

In the polar cap model the oscillations may influence the gap discharge mechanism either by quasi-periodically altering the gap characteristic (e.g. spacing) or by altering the angle between the rotational pole and the place of discharge in a quasi-periodic fashion. Another physical interpretation in the polar cap model is the sparking mechanism itself. Due to the curvature of the magnetic field a spark discharge once started travels toward the magnetic pole (e.g. Cheng, 1980) and it traverses the polar cap in 100 μs. If the spark is not restarted immediately because certain factors (e.g. shape changes of the polar cap gap) do not allow it, a certain time may elapse until conditions for a discharge are met again. This delay may be the cause of quasi-periodicities.

Harding and Tademaru (1979, 1980, 1981) have proposed that propagation of pulses through the shearing plasma at the velocity of light cylinder causes the quasi-periodicities. Addition of plasma turbulence and magnetic fields have made their model wideband under certain conditions, accounting for simultaneous multiple periodicities was not done.

In the velocity of light cylinder model the quasi-periodicities may be interpreted as bunching of emitting plasma by standing waves. Then, the wavelength of the standing wave corresponds to the separation of adjacent micropulse emission regions, which are seen, one after another, as they pass the tangential point. Much work remains to be done in all models.

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DISCUSSION

DOWNS: Why is the quasi-periodic microstructure not the result of beating between components of a frequency structure?

BORIAKOFF: The mechanism proposed by A. Harding and E. Tademaru (based on shearing plasma at the velocity of light cylinder) can be thought of as similar to this, but it is narrowband. Recent work by them includes magnetic field and turbulence and makes wideband quasi-periodicity possible.

STINEBRING: It seems important that you have seen at least a few examples of high-Q micropulse periodicity since it is easy to damp an intrinsically high-Q process after emission, but not possible to create resonance out of originally low-Q emission. Have you seen many other occurrences of this high-Q periodicity?

BORIAKOFF: Not many. They are not very frequent (one exception: PSR 0950+08 low level emission has them fairly frequently).