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A Survey for Sharply Pulsed Emissions

T. W. Cole *Division of Radiophysics, CSIRO, Sydney*
R. D. Ekers *Mount Stromlo and Siding Spring Observatories, Canberra**

The discovery of pulsars in 1967 marked the watershed of interest in short-time-scale phenomena in radio astronomy. Ionospheric scintillation on time scales of seconds, interplanetary scintillations at tenths of seconds and solar bursts of similar duration had already been studied. But with pulsars individual pulses contained subpulses of width about 10 ms, and later observations of microstructure were to show that structure with scales of 10-100 μs were present. In other areas searches for the 10-100 ms radio pulses expected to accompany the gravitational wave events resulting from stellar collapses were made, and more recently searches have been made for the radio pulse accompanying the explosion of small black holes (Rees 1977). Work in this area is summarized by O'Sullivan *et al.* (1978) and Phinney and Taylor (1979).

Sharply pulsed emissions are also relevant to the search for extraterrestrial intelligence. Although conventional wisdom in this area has concentrated on very narrow bandwidth signals at some preferred frequency, one of us (TWC) has argued to NASA (Ames) the complementary approach of searching for emissions narrow in time rather than frequency. Certainly our earthbound experience has led us to coded pulse and spread-spectrum techniques for high sensitivity in radar and communications.

In general, for all of these sources, one expects to detect a pulsed emission obscured by noise and dispersed by passage through the interstellar medium. In simple terms the pulse sweeping down in frequency at rate $\dot{\nu}$ would be smeared across a rectangular bandpass of width B by $B/\dot{\nu}$. Increasing time resolution is possible by reducing B up to the point where the rise-time of the filter ($1/B$) is of the same order at $B/\dot{\nu}$. For this minimum bandwidth $B_0 = (\dot{\nu})^{1/2}$ optimum time resolution of B_0^{-1} is possible (Ekers and Moffet 1968). More exact analysis taking into account the coherence of a narrow sweeping pulse (Cole 1972) shows that for $B > B_0$ a process analogous to diffraction through a slit produces ripples as shown in Figure 1 which are related to temporal structure on time scales of B^{-1}, i.e. much finer than B_0^{-1}. The statistics of the noise to be added to these responses depends on B and the integration time T of the detected filter output. For T of the order of B^{-1}, the output samples are Boltzmann-distributed and as T increases the distribution approaches Gaussian. Some aspects of this theory are illustrated below while a useful summary of noise statistics is found in the Project Cyclops report (1973).

A system to detect impulsive radio events has been built for us at CSIRO (by C. J. Smith) for use at Parkes. The main problem with such systems is to reject local interference. One could, over a long time, study the difference in event rates on and off the source. But a black hole explodes only once! Detection certainty would require simultaneous, widely separated detections, or some characteristic signature in the pulse. The approach taken in this search was to split the signal into two channels having different bandpass filters. The two outputs were detected and box-car integrated. The differing character of the response in the two channels would hopefully give one some information on the dispersion and frequency structure in any recorded event. Recording was on 35 mm film moving continuously past an oscilloscope triggered whenever the energies in samples in the two channels exceeded a threshold which was preset to be a constant multiple of the total power. The film record shows two sets of successive samples beginning with the strong sample which triggered the oscilloscope.

A search was undertaken at Parkes at 5 GHz with a 100 K receiver system temperature. One pair of filter responses consisted of a 10 MHz and a 2 MHz square bandpass response. A second pair available were nominally complementary 0 to 10 MHz filters in which one had a response sloping proportional to frequency and the other inversely with frequency. With a threshold set near 14 standard deviations and $T = 4$ μs, random noise excursions produced an event every few minutes. These noise events could be

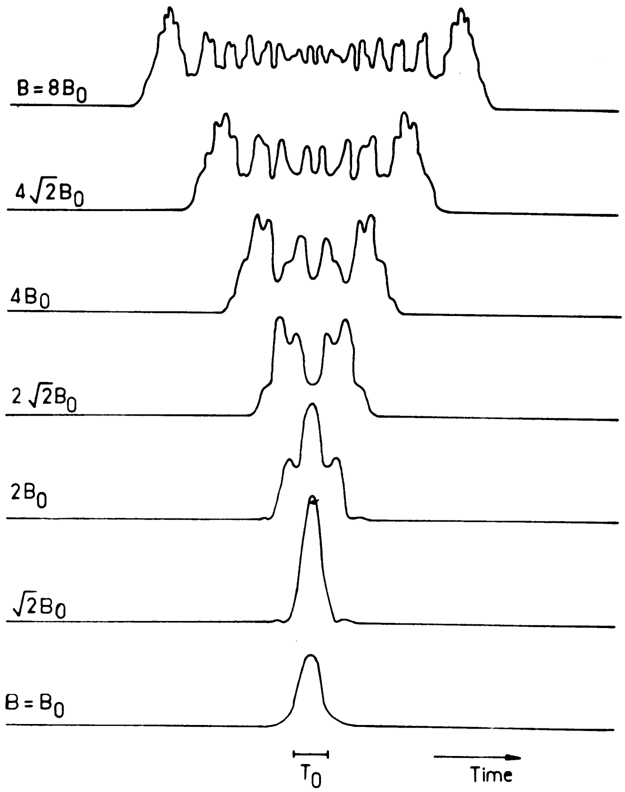

Figure 1. The impulse response of a receiver to a linearly sweeping impulse is shown for various values of the bandwidth ratio B/B_0. The interval T_0 is equal to B_0^{-1}, where B_0 is defined as the square root of the frequency sweep rate.

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*On leave from the Kapteyn Laboratory, University of Groningen, The Netherlands.

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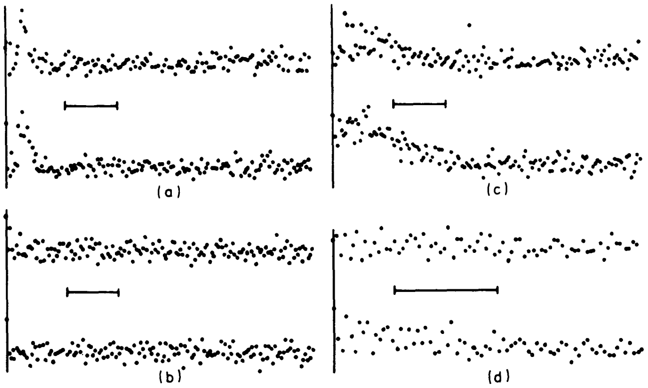

Figure 2. Successive output samples in pairs of channel outputs are shown for different impulsive events. The bars represent 100 μs. In all except (d) the upper channel is the 2 MHz and the lower is the 10 MHz rectangular filter. Note the differing noise statistics in the two channels. Event (a) is a lightning event; (b) is narrow structure in pulsar PSR 1133+16; (c) is a pulsar PSR 0833-45. Event (d) was obtained with the sloping bandpass filters on PSR 0833-45 and shows ripple detail indicating structure down to 4 μs in duration.

recognized because only the first sample was strong. The succeeding samples simply show the expected noise distributions for the bandwidth used.

Several types of real event were detected. A brief electrical storm which passed right over the telescope produced lightning events such as that in Figure 2(a). These show structure down to 4 μs and typically lasted 100 μs.

Two pulsars were observed with the system. As expected from the work of Bartel (1978) at Bonn, PSR 1113+16 shows detail on time scales of 6 μs. As shown in Figure 2(b), the sensitivity at Parkes at the high frequency of 5 GHz was only marginally sufficient to confirm the results of Bartel. Somewhat higher signal-to-noise was at times possible on individual pulses from the Vela pulsar PSR 0833-45. Two events are shown in Figures 2(c) and 2(d). That in 2(c) with the 2 and 10 MHz filters indicates pulses of duration 50 μs, comparable with the 40 μs dispersion smearing of a 10 MHz bandwidth at 5 GHz. The value of B_0 for the observation was 500 kHz, so it is interesting to note the diffraction structure in the event of Figure 2(d) observed with the sloping bandpass filters. The curves of Figure 1 are not directly applicable to these sloping bandpass filters, and since their response is unknown to sufficient accuracy, exact modelling is precluded. However, it does appear clear that non-random rippling has been seen, indicating microstructure in PSR 0833-45 on time scales down to 4 μs.

Fifty hours spent observing globular clusters, X-ray sources, dense regions in the Magellanic Clouds and the galactic centre failed to produce any events which could not be attributed to noise. But a preliminary search for extraterrestrial intelligent signals from the nearer G- and K-type stars did produce one event which should be reported. While the telescope was pointed at the G5-type star 82 Eri the event shown in Figure 3 was recorded. It is not attributable to lightning and is the only non-explicable event seen in three days of observing. The total

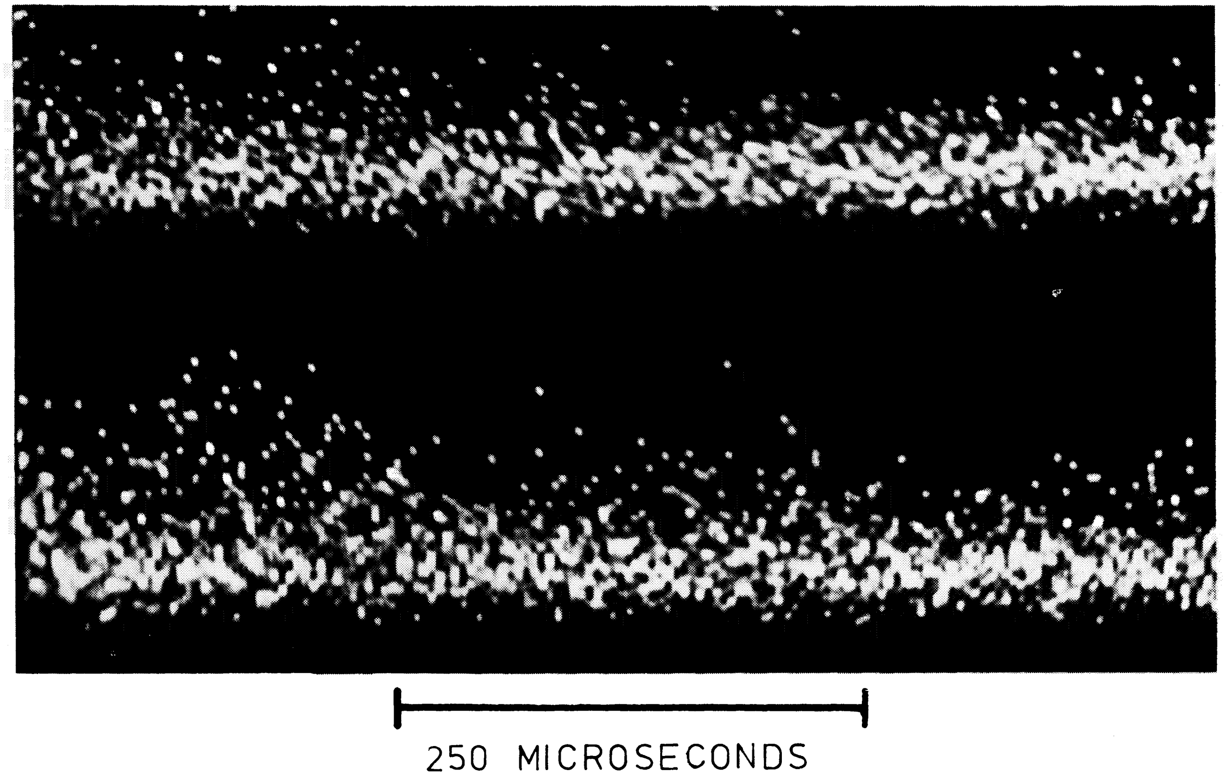

Figure 3. This non-random event was observed from star 82 Eri, as discussed in the text. The 2 MHz channel is above the 10 MHz channel and the event was recorded as the superposition of a number of closely-spaced events of total duration probably 1 ms.

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