SHORT COMMUNICATIONS

THE MEASUREMENT OF STATISTICAL PROPERTIES OF RADIO NOISE USING PULSE TECHNIQUES

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Abstract

The statistical properties of radio noise have been investigated by means of a wide-band radio receiving system and techniques similar to those employed in nuclear physics. Measurement of the amplitude probability distribution of broad-band noise at a rural location has shown that it can be represented by a Rayleigh distribution over a much wider dynamic range than is commonly observed. The time distribution of the largest observed noise amplitudes appears to be non-random.

The characteristics of background radio noise have normally been measured with bandwidths in the audio range, values ranging from 200 Hz to 10 kHz being able to cover most normal measurements (Horner 1964). Although this range is convenient for conventional analogue measuring devices, much background radio noise is basically impulsive in character and the use of low bandwidths smooths and causes overlapping of individual impulses, thus eliminating information on the physical nature of the noise. Middleton (1972) has pointed out that "essentially nothing adequate appears to have been done" regarding the measurement of wide-band noise as it actually occurs. A characteristic feature of wide-band measurements is that any increase in the bandwidth within which the measurements are made leads to signals that are more obviously pulse-like in character (e.g. a bandwidth of 10 MHz gives pulses $\sim 0\cdot 1\ \mu$s in width). This is the kind of pulse that is common in nuclear physics and it seemed promising to attempt to apply conventional nuclear pulse techniques to the study of the properties of radio noise. It is the purpose of this note to report the results of a successful preliminary study of the possibilities of such methods. The study is presently being continued.

The statistical properties of the radio noise background at 50 MHz have been investigated at the Buckland Park field station of the University of Adelaide, which is located in a rural environment some 15 miles from the limits of suburbia. In particular, the amplitude probability distribution function (APD) has been investigated with bandwidths up to 10 MHz and the noise pulse spacing distribution (PSD) has been determined with a 10 MHz bandwidth for spacings between 200 ms and 100 s.

The 50 MHz receiving system used consisted of a half-wave dipole $\frac{1}{4}\lambda$ above ground, a receiver, and a variety of recording devices. The APD was initially determined for bandwidths below $2\cdot 5$ MHz using a transient recorder, Biomation Int. (Palo Alto, Calif.) model 610B, as the noise recording device. This transient recorder

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continually digitizes and stores an input waveform which can be later output slowly in an analogue form to a chart recorder. The device has a maximum bandwidth of 2·5 MHz. To determine the input APD, measurements were made by visual inspection of the output chart record. At least 500 independent measurements were made for each bandwidth investigated. The bandwidths were between 6 Hz and 2·5 MHz, and it became clear that at this particular site the APD could be represented by a Rayleigh distribution down to well below the 1% probability level.

A Rayleigh distribution is invariably found for the high probability regions of noise APD's (Disney and Spaulding 1970). This distribution is to be expected for the envelope of smoothed impulsive noise and normally extends to a level which is dependent on the bandwidth (i.e. degree of smoothing). At regions of low probabilities, the APD is found to depart increasingly from the simple Rayleigh distribution and this region is often called the "power Rayleigh" portion (Spaulding *et al.* 1962). For typical urban, suburban, and rural conditions the transition from Rayleigh to power Rayleigh conditions occurs somewhere in the 10% probability region (Spaulding *et al.* 1971).

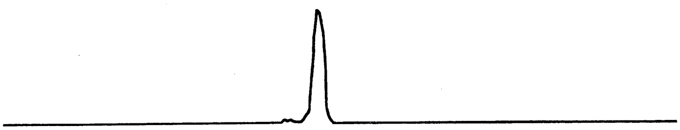

Fig. 1.—Copy of a radio noise pulse recorded by the transient recorder. The pulse is saturated but very little other noise is above 1 part in 64 full scale. The trace length is 25·6 μs.

Visual measurements of the APD cannot greatly extend the range of measured probabilities due to the rapidly increasing chart-reading effort required and, for this reason, pulse-counting techniques were employed to extend the APD at 10 MHz bandwidth. At very low probability levels and large bandwidths, the noise waveform appears as a succession of pulses most of which are bandwidth limited (to at least 2·5 MHz). An example of such a pulse is shown in Figure 1. This figure was obtained using the Biomation transient recorder and illustrates the usefulness and a drawback of the device. The trace is equivalent to an oscilloscope trace on a 25·6 μs total time base and was obtained directly from the device without the inherent errors of photography and subsequent enlargement. However, in order to record the full amplitude of the pulse it was necessary to use the device with such gain that most background noise was below the level of the least significant bit of the analogue to digital converter, thus producing apparently zero background noise. Such pulses may be detected and measured by simple pulse-counting techniques with the use of single- or multi-channel analysers or discriminators. A discriminator was therefore used and APD's were measured for 10 MHz bandwidth noise over the range of $> 5 \times 10^4$ pulses per second to $>$ 10 seconds per pulse. At the higher rates, overlapping pulses might be expected to distort the APD slightly but in practice the major error here was the dead time of the discriminator used, and this limited useful rates to below 50 kHz. Such errors are well understood and the results can be readily corrected for them.

Figure 2 shows three typical APD'S measured with widely different receiver bandwidths. The bandwidths that gave the data sets B and C (130 kHz and 10 MHz) are much larger than normally employed in determining APD's. It is clear that the Rayleigh region of the APD extends to very low probability levels before the power Rayleigh region sets in. The power Rayleigh portion is very time-dependent and, since it is necessary to count pulses for 10 s or more to investigate this region, the results appear highly variable, although the onset of the power Rayleigh region rarely occurs for rates above $10\ s^{-1}$. It was subjectively evident that most of the power Rayleigh pulses occurred in bursts, and on occasions it was possible, when no obvious bursts were observed, to continue counting pulses (at rates less than $10^{-1}\ s^{-1}$) which continued the Rayleigh region of the APD. Although the problem has not been investigated systematically, the occurrence of the power Rayleigh region of the APD did not appear to bear a simple relationship to human activity, in that quiet times were often found in week days while weekends could be exceptionally noisy.

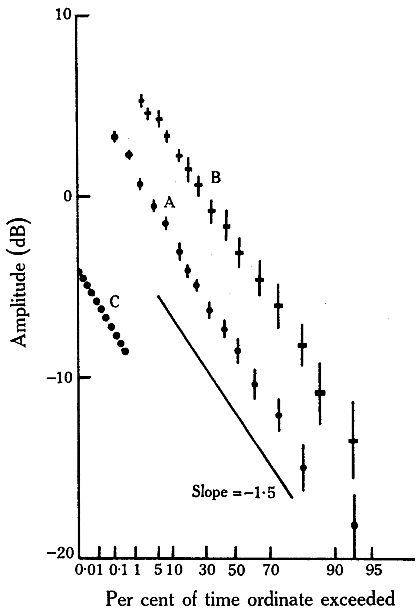

Fig. 2.—Three typical radio noise APD's at 50 MHz with bandwidths of:
A, 63 Hz;
B, 130 kHz;
C, 10 MHz.
The graphical scales are such that a plot of a Rayleigh distribution gives a straight line of slope $-1\cdot5$, as indicated in the figure. The three data sets are not normalized to each other.

In order to obtain a better model of the low probability region of the APD it is necessary to have a numerical description of the times of occurrence of the noise pulses, and therefore the PSD has been measured for pulse spacings ranging up from 100 ms. The output pulse of the discriminator was used to put a pulse on a chart recorder and the pulse spacings were measured by hand. With a maximum chart speed of $1\ cm\,s^{-1}$ the minimum measurable spacing was 100 ms. The PSD was measured at a number of times of the day and, for convenience, at a number of discrimination levels. In general, the discrimination level was set to give roughly the same pulse rate for each time of day, and this involved a maximum variation of about 13 dB between the quietest and noisiest periods. Figure 3(*a*) shows four PSD's obtained in this way. There does not appear to be any simple power law, exponential function, or Rayleigh distribution for the data. However, it is striking that, although the noise background varies considerably over the individual measurements, the *shape* of the distribution for a given pulse rate is remarkably constant. It has been pointed out many times (Disney and Spaulding 1970) that radio noise bursts have a PSD which does not correspond to randomly distributed pulses, i.e. it is not purely exponential. It is clear that this still applies for wide-band noise even at these very low rates. Owing to experimental uncertainties, it is always possible to fit an exponential distribution to a limited range of the data. A range of potential significance is that which includes the largest amplitudes. The data set B in Figure 3(*b*), a quiet-night measurement, gives a fit over the widest dynamic range (2–20 s pulse spacing) with an average spacing of about 3 s. On the other hand, for the noisy week day measurement A of Figure 3(*b*) it is doubtful if an exponential can be meaningfully fitted at all.

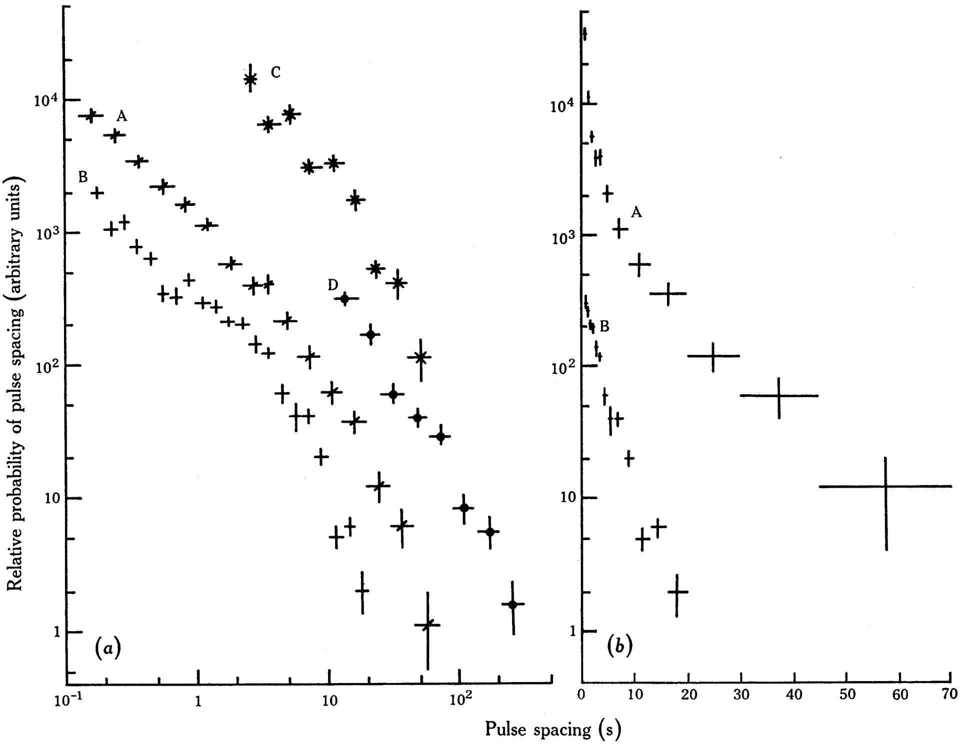

Fig. 3.—Examples of PSD's obtained. The four data sets in (*a*) were taken at independent times in November 1972: A, 1430 hr Tuesday 21; B, 0000 hr Wednesday 29; C, 1200 hr Saturday 11; D, from 1200 hr Wednesday 15 to 0300 hr Thursday 16. Noise discrimination levels with respect to B were +13, +3, and +7 dB for A, C, and D respectively. In (*b*), the sets A and B are displayed on log–linear scales.

It appears then that, at this particular site, the power Rayleigh region of the APD occurs at a rather low probability level. This may be a measure of the lack of man-made interference at the site. The APD can be measured satisfactorily to very low probability levels using simple pulse detection techniques. In this region the pulse spacing distribution for a given pulse rate is largely independent of pulse amplitude and even here it is rather artificial to describe the noise process in simple terms.

Acknowledgment

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