SYNCHRONOUS ANALYSIS OF STATISTICAL PARAMETERS OF THE ATMOSPHERIC NOISE

Taketoshi NAKAI and Masahiro NAGATANI

Abstract

Synchronous analysis of the four statistical parameters has been realized by the introduction of a digital computor system specially designed for the measurement of atmospheric radio noise measurement of a given short duration. The four statistical parameters are the parameters that give both the amplitude characteristics of the radio noise and the time characteristics on the time sequence of the radio noise intensity, namely they are amplitude probability distribution, crossing rate distribution, probability distribution of duration of pulses, and probability distribution of the occurrence time interval between pulses. In this paper are described the system that measures the atmospheric radio noise and the system that processes the digital data including the process of conversion from analogue to digital. The four statistical parameters have been analyzed with the aid of a new data processing system that can be applied to the atmospheric radio noise measurement. Synchronous analysis of the four parameters is expected to lead to a precise investigation on the close corelation between them. In this paper the suggestions being made on these points are that : The shape of the amplitude probability distribution can theoretically be determined from the shape of the corresponding crossing rate distribution. A particular curve of the crossing rate distribution is shown on a graph, because the corresponding amplitude probability distribution follows a log normal law. A data is shown, which shows a possible transformation between the probability on A. P. D. and the crossings per second on C. R. D.. The probability distributions of duration of pulses and those of the occurrence time interval between pulses are shown as a function of threshold values that cover 80 dB dynamic range of amplitude variations, where surprisingly good resemblance can be found between probability distributions of the occurrence time interval between pulses in day times, and those in night times.

1. Introduction

The noise process of the atmospheric radio noise can be thought to be a kind of stochastic process. Accordingly, the amplitude variation in the noise process, for example, can be described most completely in terms of the amplitude probability distribution (A. P. D.) or the probability density of amplitude of the instantaneous voltage. "What kind of statistical parameters must be measured to attain the aim of completely describing the process of atmospheric radio noise?" Since the past I. G. Y. in 1957, the development in the experimental observation has been remarkable in the research field of the atmospheric radio noise. Not only the simple moment, such as average voltage, R. M. S. voltage of the noise amplitude, but also the four statistical parameters have been extensively measured: amplitude probability distribution (A. P. D.), crossing rate distribution (C. R. D.), probability distribution of duration of pulses (P. D. D. P.), probability distribution of the occurrence time interval between pulses (P. D. O. T. I. P.). Observations of these parameters were made by many workers with various electronic devices, in different parts of the world, in different seasons, at different frequencies (Clark 1960, 1962; Horner and Harwood 1956, 1958; Harwood 1958; Nakai 1958, 1961, 1963, 1969; Watt and Maxwell 1957; Yuhara et al. 1956; A. W. Sullivan 1956). As a result of tremendous number of observations, large masses of the data were accumulated on a worldwide basis. We, in the present state, can get much more information on the properties of the atmospheric radio noise than we have had. It has been very unfortunate, however, that the condition of synchronization has not been satisfied with the measurement or analysis of the four different statistical parameters up to the present. We have not been able to say that "We have a means for readily measuring or analyzing the four statistical parameters from a given sample of the atmospheric radio noise of short duration". Accordingly, the synchronization of the four parameter measurement has been a continuous demand in the radio noise study up to the present. The significance of the synchronization will be summarized as (1) the most effective data can be obtained for a given sample of the atmospheric noise of short duration, and (2) we can get larger possibilities for a precise comparison between different parameters and for an establishment of close relations between them.

Recently, we have succeeded in the synchronous analysis of the four statistical parameters by using a digital computor system at Toyokawa in Japan, and thus, the details of it will be described in this paper.

2. Principle of synchronous analysis

There are several ways of synchronous measurement or analysis of the four statistical parameters of the atmospheric radio noise :

(1) the first way is to utilize the electronic devices of four types each of which satisfies the need for measuring one of the four statistical parameters. The principle of synchronous measurement, in this case, is very clear, and the atmospheric radio

noise received at the same antenna is picked up at the inputs of four electronic devices of different types being connected in parallel. However, this way accompanies the complexites and difficulties which may be introduced in alignment of thresholds between four different electronic devices, because the settings of a series of thresholds must be made in measuring any one of the four statistical parameters. In addition to this, the need of the use of recorders of different types in synchronously measuring the four parameters may require a surplus carefulness and laborious efforts in rapid trement of data.

(2) More advisable, as compared with the way (1), is, with our view to synchronously analyze the four statistical parameters, to employ a digital computer system which is provided with an A. D. converter and bulk storage devices. The function of a receiver, in this case, is simple i. e., which is to receive the atmospheric noise at an antenna, to amplify the noise voltage, to filter the noise-energy within a given frequency pass band-width and to perform the function of peak-detection of the noise voltage at the output of the receiver. The voltage of the noise envelope is transmitted to the input of the A. D. converter, by the function 'of which they are evaluated with a preset sampling period of a given short duration. Large masses of sample amplitude height data are fed to a magnetic disk storage and stored on it. The program must be written for processing data stored on the magnetic disk storage in the digtsal computer system, which performs the function of analizing all four statistical parameters.

(3) There is another way of synchronously analyzing the four statistical parameters, in which a magnetic tape recorder intervenes between the receiver and the digital computer system or the A. D. converter, in contrast to the direct connection found in the way (2). The way (3) does not permit "real time" data processing." However, the employment of a portable storage device like a magnetic tape recorder make it possible to separate the time and place for atmospheric radio noise measurement from time and place for data processing in the digital computer system. Accordingly, the way (3) has often an advantage over the way (2), because the location of receiving station of the atmospheric noise, in this case (3), are not limited within the distance from which data transmission is possible to the building, where is installed a digital computer system, whether it may be on a wireless or a wire communication.

3. Apparatus and measurement

The measurement of the atmospheric radio noise were made at Toyokawa from August 15 to 25, in 1968. The block diagram of the noise measuring- system and that of the data processing- system are shown in Fig. 1 and Fig. 2 respectively. The atmospheric radio noise at 50 KHz (a central frequency) is received using a 8 meter vertical antenna in 1 KHz band width between 3 dB drop points. The objective of the measuring system, as is shown in Fig. 1, is faithfully recording the voltage of the noise envelope on a magnetic tape. Much attension, here, has to be paid to the faithful recording, because the amplitude variations of the noise envelopes can be expected, from our experience, to have a dynamic range nearly 80 dB wide or larger than this, as described elsewhere (Nakai, 1969).

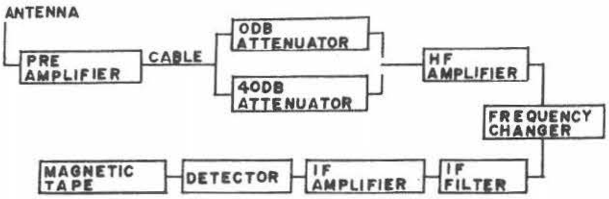

Fig. 1 Measuring system of the atmospheric noise

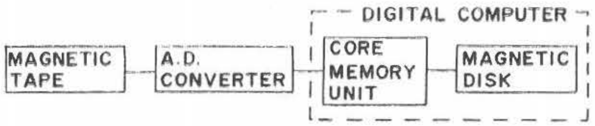

Fig. 2 Data processing system

Now, the linear dynamic range of the voltage variation with the receiver is about 40 dB and the corresponding voltage at the output of the receiver from 30 to 3000 millivolts. The magnetic tape recorder is of a FM type, of the tape speed 19 cm/-second and the frequency characteristics of response is flat from d.c. to 2.5 KHz. A linear dynamic range is also 40 dB in recording voltage variations on the magnetic tape.

It is completely clear from the above that we cannot amplify straightforward and record the 80 dB voltage variation of the noise through a combination of the receiver and magnetic tape recorder without any saturation. Therefore, two 80 second interval measurements were made respectively on the two different settings of attenuator 0 dB and 40 dB at the HF stage, as is shown in Fig. 1. We can record on a magnetic tape, the two dynamic ranges, low level 40 dB — voltage variation during the first 80 second interval and high level 40 dB — voltage variation during the second 80 second interval without any saturation.

First, the 0—dB attenuator noise envelope recorded on the magnetic tape is reproduced and transfered to the input of the A. D. converter. The voltage variation at the input is evaluated with a sampling period 40 μsec for 60 seconds time length, which is of course shorter than 80 second time length. Total data thus amounts to 1, 500,000, each of which is expressed by a 3 digit decimal number with an error $\pm$ 1. These large masses of the digital data, as is shown in Fig. 2, are brought to a high speed core storage (main memory) of the digital computer system through a direct access control (DAC). Digital data temporaly stored on a core storage are transfered to a magnetic disk storage (MD), which is random access device with a storage capacity of 2,000,000 digital data. Secondly, the procedure, which involves reproducing, sampling, and storing, is repeated again for the 40-dB attenuator noise envelope, after the data processing of the stored data for the 0-dB attenuator noise envelope has been performed in the digital computor system.

4. Results of measurement

4. 1 A. P. D. and C. R. D.

The program has been composed with our view that the aim is to derive the four statistical parameters synchronously by the use of the atmospheric noise envelope record of 60 seconds duration, so that it performs the function of processing large masses of digital data on a magnetic disk storage, which results in synchronous derivation of the four statistical parameters. Four parameters obtained by processing the program in the digital computor are A. P. D., C. R. D., P. D. D. P., and P. D. O. T. I. P., which satisfy the condition of synchronous analysis of the four statistical parameters of the atmospheric noise envelope of 60 seconds duration.

It has been found, as is naturally expected, that each of the four parameters derived by the use of the combination of the receiver, magnetic tape recorder and digital computor, has a good resemblance to that measured by many workers with the aid of the ordinary electronic devices. An example of A. P. D. analyzed synchronously, is shown on a log-normal graph in Fig. 3, where the ordinate represents the probability (%) with which the noise envelope voltages exceed on threshold values indicated on the abscissa.

Let us give a short note on the signs written on the graph and on a non-linear range of the voltage variations, which apply throughout this paper. ITH (2) and ITH (H 32) represent 2 millivolts and 32×100 millivolts in terms of voltage at the input of the A. D. converter. The numerical letter in unit of dB on the abscissa represents the threshold dB/ 1 millivolt. A linear range of voltage variations with the total system consisting of the receiver, magnetic tape recorder and data processing system ranges from 20 to 100 dB on the abscissa. While a non-linear range lies in the range less than about 20 dB, which is under influence of the set noise.

The curve can be approximated with two composite lines on a log-normal graph, in which each section of the straight lines follows a log normal distribution, and the two standard deviations are found to be 12.5 and 15 dB. The corresponding crossing rate distribution is shown in Fig. 4, where the ordinate represents the number of crossings per minute with which the noise envelopes traverse in one direction threshold

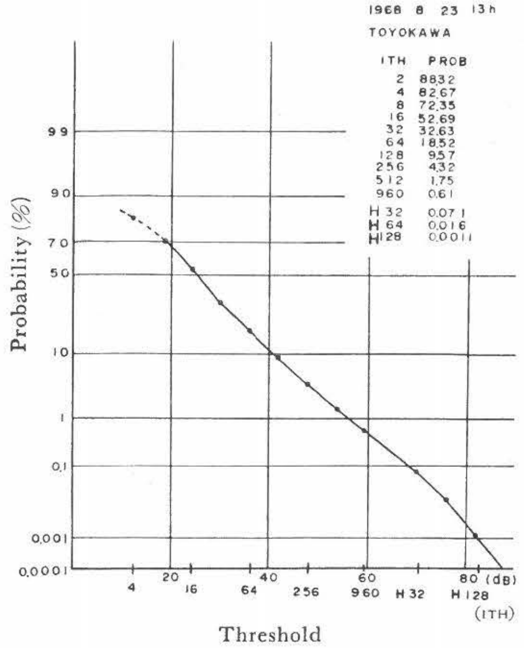

Fig. 3 Amplitude probability distribution (A. P. D.) of the atmospheric radio noise—log normal graph

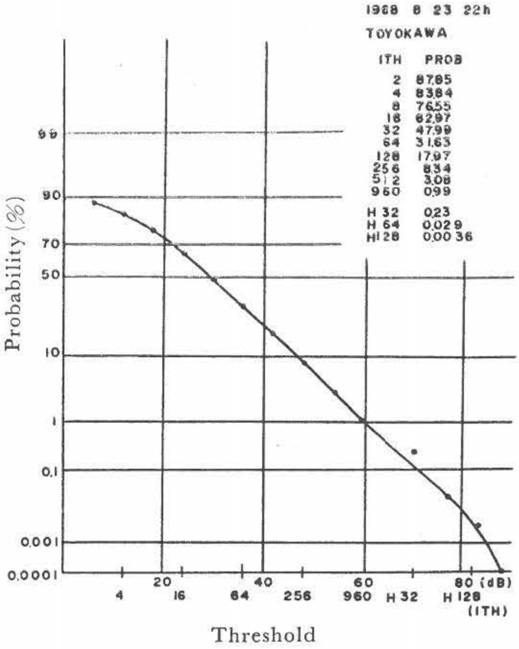

Fig. 6 A. P. D. which follows a log normal law—log normal graph

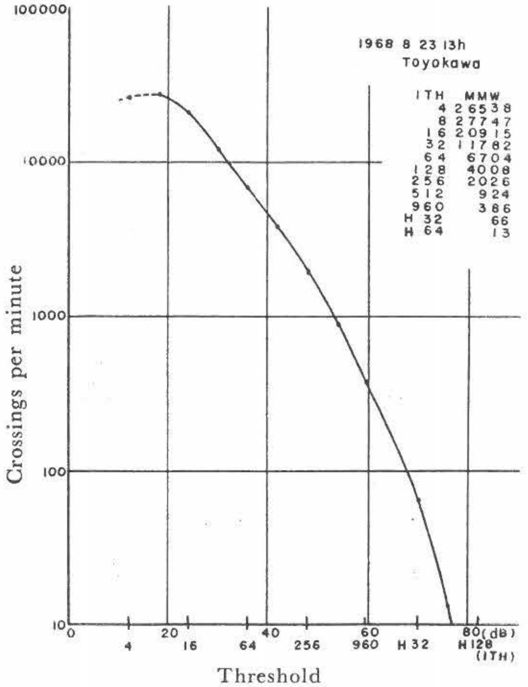

Fig. 4 Crossing rate distribution (C. R. D.) of the atmospheric radio noise—logarithmic graph

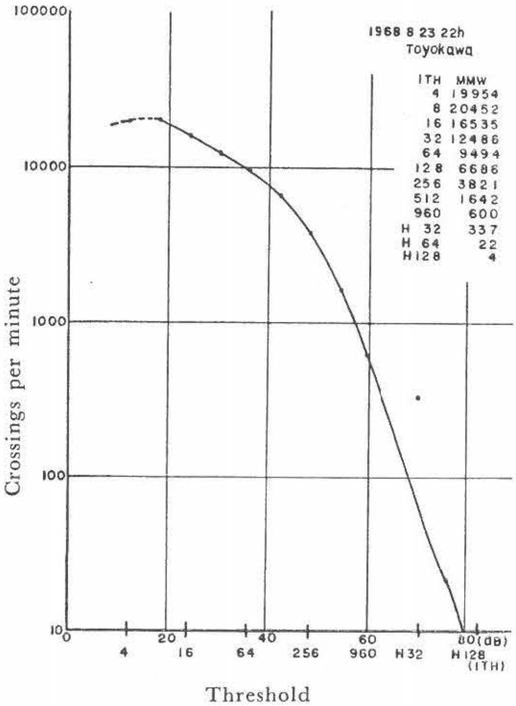

Fig. 7 C. R. D. corresponding to A. P. D. which follows a log normal law

values indicated on the abscissa. It is also represented by the sign MMW on the graph. It is well established that the curve of C. R. D. can also be approximated with a composite curve consisting of two or three straight lines lying in the range less than 80 crossings per second. Therefore a power function can be so adapted as to be the representation of each straight line section of the composite curve with logarithmic scales on both coordinates. But this particular example can be approximated with a composite curve consisting of three straight lines, the slopes of which can be estimated to be 1.05, 1.43 and 3.63 from left to right on the graph. From the shape of the crossing rate distribution, we can reasonably suppose the corresponding distribution of peak amplitudes of the impulses arriving at the antenna, as was described elsewhere (Nakai, 1968). Accordingly, the corresponding distribution of peak amplitudes of the pulses, in this case, may be thought to consist of three power functions whose exponents are also 1.05, 1.43 and 3.63.

Let us consider the significance of synchronous analysis of A. P. D. and C. R. D. being applied to the atmospheric noise of short duration. "What relation would be found between A. P. D. and C. R. D. ?". Several authors already derived A. P. D.'s by making some assumptions. For example, a way of the derivation will be given as follows : The atmospheric impulses are supposed to arrive at an antenna with time spacings determined by the exponential law, and the distribution of peak

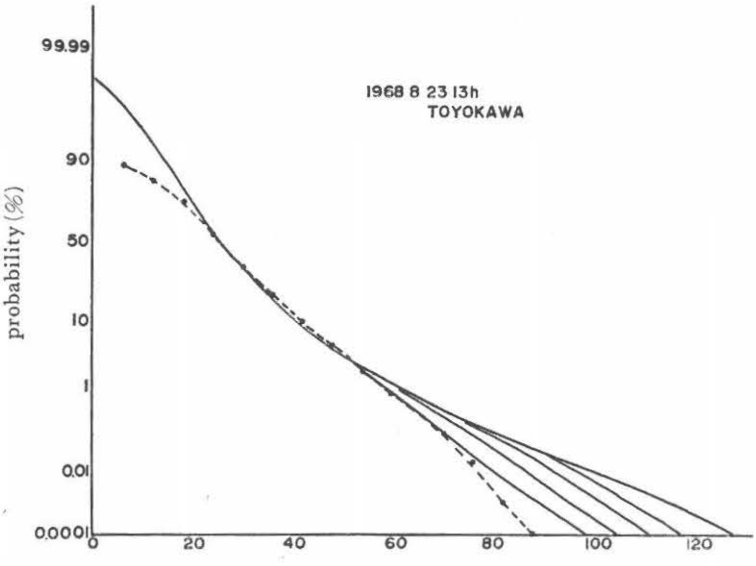

Fig. 5 Graph showing agreement between theoretical—and analyzed A. P. D.'s — a series of theoretical curves calculated for parameters $r_1=1.05$, $r_2=2.0$ of the two power functions and for various intersection at 12 dB intervals of two power functions

amplitudes of the impulses is supposed to be defined by a specific function. The receiver response is also specified. Then the A. P. D. can be derived on the assumptions being made of these items. One of the authors (Nakai, 1966) derived A. P. D.'s by supposing that the distribution of peak amplitudes of the impulses is expressed by a composite function consisting of two power functions that have their respective different exponents r_1 and r_2. Fig. 5 shows a comparison between the analyzed and the theoretical A. P. D.'s, where broken line indicates the analyzed curve shown in Fig. 3, while full lines represent theoretical curves. It is seen in Fig. 5 that the analyzed A. P. D. in most parts of the curve agrees with one of theoretical A. P. D.'s derived from given two exponent values $r_1=1.05$, $r_2=2.0$, even though significant discrepancy is found at very low probability range. Remarkable discrepancy would be thought to be the disagreements between r_2 (theory) and r_2, r_3 (analysis). We can of course neglect other discrepancy found in the threshold range less than 20 dB because of a non-linear range. The r_1 value above has been chosen, because the exponent of a power function is equal to 1.05, which is a main component of the corresponding C. R. D. as shown in Fig. 4.

The other examples of A. P. D. and the corresponding C. R. D. are shown in Fig. 6 and 7. The illustrated A. P. D. nearly follows a log normal distribution over 60 dB threshold range, with a standard deviation 15 dB. We can here again neglect an appreciable discrepancy from the log normal distribution in the threshold range less than 20 dB with the same reason described above. A plot of the analyzed value on the right hand side on the graph shows a remarkable discrepancy from the full line, which is due to the set noise in measuring the high level 40 dB voltage variations at the attenuator setting of 40 dB. "What is the nature of the corresponding C. R. D. to the A. P. D. that follows a log normal law more than 60 dB ?" It is seen in Fig. 5 that the C. R. D. has an usual shape that can be approximated by two composite power functions and their exponents are found to be 1.14 and 3.08, respectively corresponding to the left half and to the right half of the composite curve. But, as compared with the case of the approximation in Fig. 4, a good approximation holds in the threshold range from 45 dB to 80 dB and the approximation range is only 35 dB, moreover, overlapping between the impulse responses become remarkable towards the threshold range 20 to 40 dB, as also infered from the behaviors of the synchronously analyzed P. D. D. P.'s shown in the latter part of this paper. Therefore, we cannot reasonably suppose the distribution of peak amplitudes of the impulses arriving at the antenna in the threshold range 20 to 40 dB. The final conclusion of the above discussion is that : We, in the present state, cannot reasonably suppose the distribution of peak amplitudes of the impulses over the threshold range 50 or 60 dB, which of course reduces to the fact that we cannot make use of the C. R. D. shape in deducing it for case of Fig. 6 by the reason described above.

4. 2 P. D. O. T. I. P.

The probability distribution of the occurrence time interval between pulses has been obtained from syncnronous analysis of the atmospheric noise of 60 seconds duration together with the other three statistical parameters. The distributions in day times and those in night times have been analyzed as a function of the threshold value and are shown in Figs. 8 and 9 respectively. We can easily decide whether a distribution follows the Poisson distribution law, because the Poisson law can be represented by a straight line with a slope —1 on the Rayleigh graph. Accordingly, we find that the particular distributions does not follow the Poisson distribution except the cases, thresholds 16 and 32. While the comparison between the curves in Figs. 8 and 9 show a very surprising fit, which shows that the statistics of the occurrence time interval between pulses is very stationary throughout day and night times in summer season, where a new symbol PROB represents the probability with which the noise envelopes exceed the threshold specified on the graph.

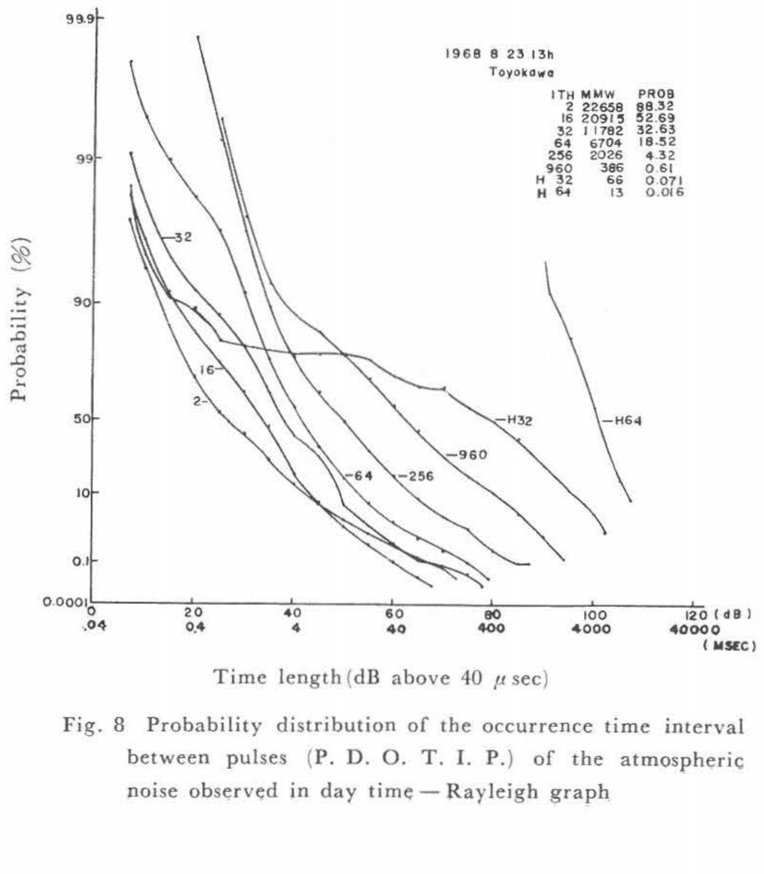

Fig. 8 Probability distribution of the occurrence time interval between pulses (P. D. O. T. I. P.) of the atmospheric noise observed in day time — Rayleigh graph

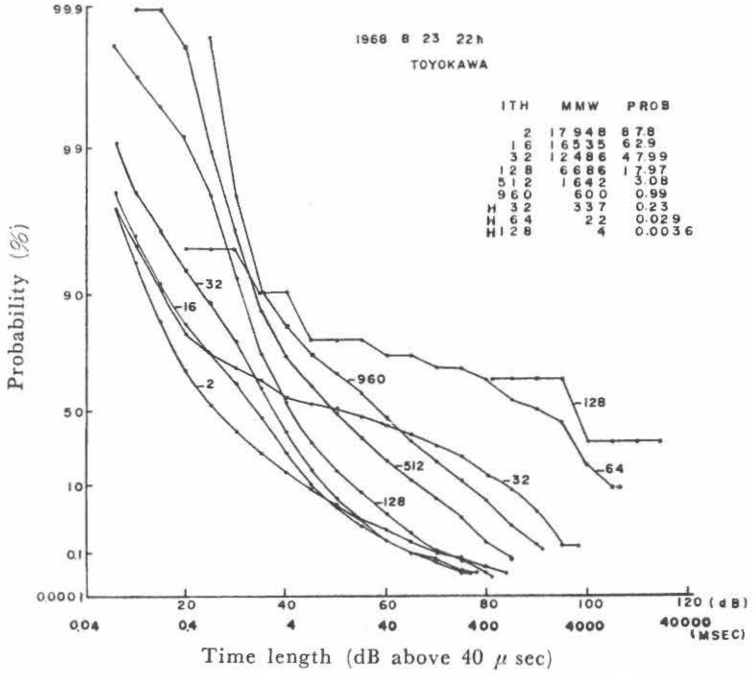

Fig. 9 P. D. O. T. I. P. observed in night time—Rayleigh graph

Fig. 10 shows the probability density of the occurrence time interval between pulses, where the ordinate represents the occurrence frequency of pulse and the abscissa the interval time length.

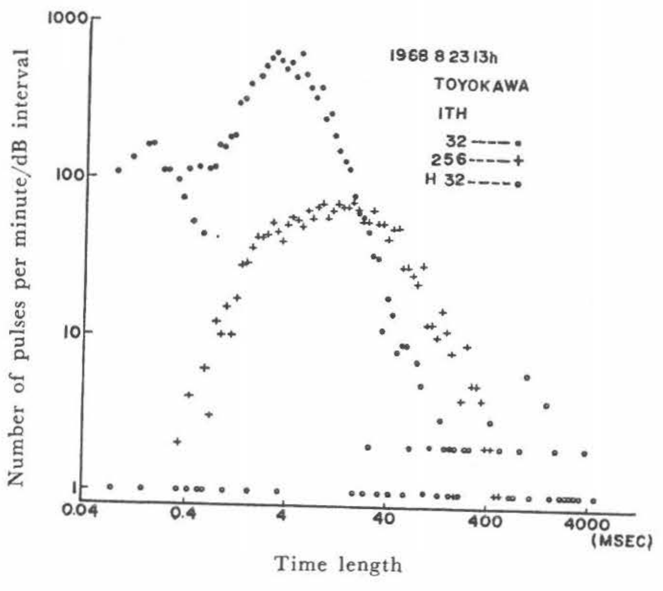

Fig. 10 The probability density of the occurrence time interval (dB above 40 μ sec)

4. 3 P. D. D. P.

P. D. D. P.'s as a function of threshold values are shown in Fig. 11. As it is seen in the figure, the difference between the shapes of P. D. D. P.'s at intermediate, and those at high, thresholds is not significant. The average duration of the pulse has been calculated as a function of threshold, and is shown in Fig. 12. It is found that there is a region, as shown in Fig. 12, where the average duration does not change significantly. The fact is very useful to the formation of a transformation between the probability on A. P. D. and the crossings per second at high threshold, as it was once calculated by Nakai (1963).

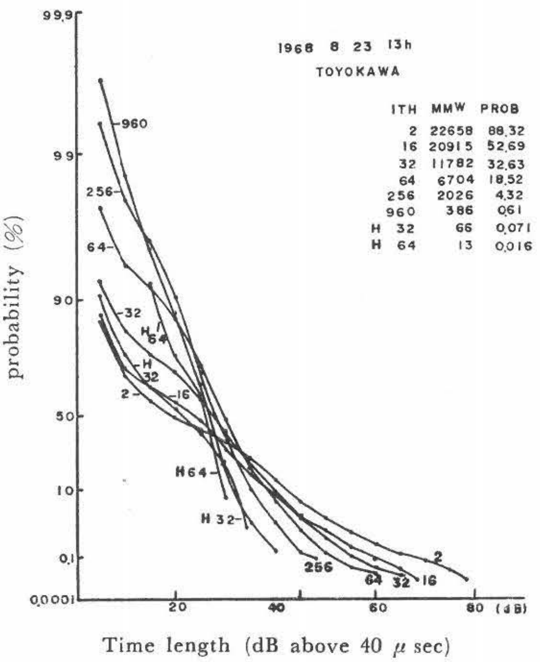

Fig. 11 Probability distribution of duration of pulses (P. D. D. P.) of the atmospheric radio noise — Rayleigh graph

5. Conclusion

Synchronous analysis of the four statistical parameters has been realized on the observation of atmospheric noise of a given short duration. We can readily analize the four parameters, where the analysis is, in a certain sense, equivalent to the symultaneous measurement of these parameters. We have shown a few examples of result of the present analysis, where we can find not a few suggestions for the further study of the noise phenomena.

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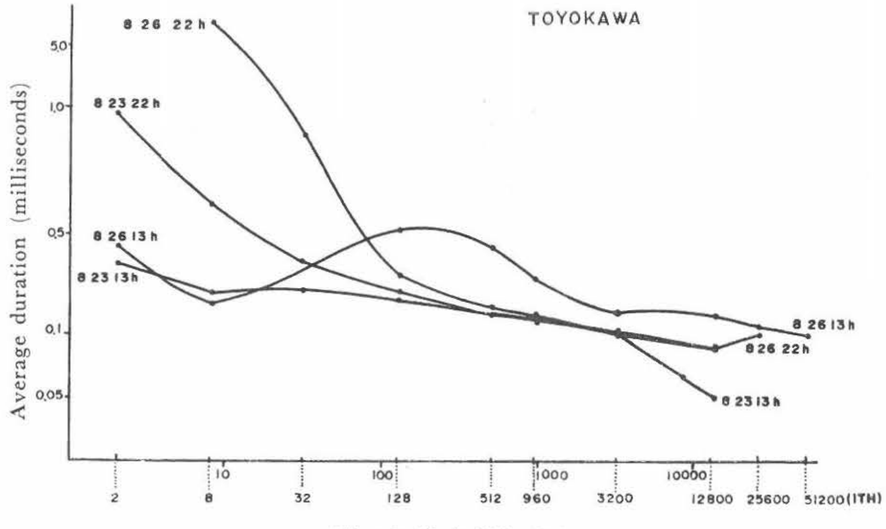

Fig. 12 Graph representing average duration as a function of the equivalent threshold at the input of the A. D. converter

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