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Atmospheric Radio Noise Measurements in India

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A review is given of the instruments developed for the study of the amplitude and time characteristics and the structure of radio noise bursts resulting from lightning flashes. The use of such instruments, suitably modified for a study of thunderstorms, thunderclouds, convection cells in thunderclouds and lightning is discussed. Most of the parameters investigated have a log-normal distribution. This log-normal law is an approximate representation, but the accuracy realized is of the order of 90%. An integrated account incorporating the latest results on atmospheric noise data for the land mass of India and on the characteristics of tropical thunderstorms and lightning, is furnished.

1. Introduction

ELECTRICAL discharges accompanying lightning flashes in thunderstorms radiate a significant amount of energy over a wide range of the electromagnetic spectrum. These radiations are propagated through space in accordance with the known laws. The nature and magnitude of these radiations received at a point are determined by the source characteristics, viz. the location of thunderstorms, their growth and decay, and the flashing characteristics of the lightning discharge. When these radiations from lightning flashes as received at a point are picked up by a receiver tuned to a certain frequency with a specified bandwidth, the output in the receiver is called atmospheric radio noise. To the extent to which the aerial and the associated circuits of the receiver have an effect on the waveform of the received radiation, the characteristics of atmospheric radio noise will differ from those of the original radiation.

The output in the receiver arising from one complete flash in a lightning discharge is a 'noise burst' having a structure of its own. Investigations on the structure and characteristics of such noise bursts, viz. both amplitude and time characteristics, and the collection and assessment of data based on such investigations are of real significance for assessing the interfering effect of atmospheric radio noise to the different classes of services in the various frequency bands. If such studies are supplemented by a proper study of thunderclouds and thunderstorms, the results can be much more useful. With this end in view, a series of investigations have been carried out in India over a period of two decades. The object of this paper is to give an integrated account of the results of such investigations, highlighting the results of experimental and theoretical work done during the last two years.

2. Work on Atmospheric Noise in India

The land mass of India extends from the tropical to the temperate regions and is a well-known global centre of intense thunderstorm activity. Therefore, the local and near sources of the noise play a more important role in determining the characteristics of atmospheric noise in India than in countries located at very high latitudes. Consequently, the severe interference arising from atmospheric radio noise to communication systems has attracted considerable attention over a period of three decades. The All India Radio, the Department of Civil Aviation and the Department of Wireless Planning & Coordination have evinced sustained interest in studies of atmospheric radio noise. The first measurements were in the mf and hf bands and were largely confined to high amplitude noise impulses[1-4]. The Radio Research Board of the United Kingdom carried out worldwide measurements of atmospheric radio noise and, for this purpose, included Calcutta, Delhi and Colombo in the list of observation stations. In their method, a signal electronically keyed at the rate of 10 words per minute was fed along with the received atmospheric noise. The strength of the signal was gradually raised till the observer recorded them with 95% of the time intelligibility. Measurements were taken every hour at a predetermined number of spot frequencies with a suitably chosen bandwidth. The results have been incorporated in a special report[5]. A modified form of this method suitable for broadcasting was developed in India and extensively used by the All India Radio for measurements at a number of places[6]. The National Bureau of Standards, USA, designed the ARN-2 noise recorder for measuring atmospheric radio noise in an objective way[7]. This recorder has been in continuous use at Delhi for collecting the required data on a worldwide basis. Utilizing the data collected with the ARN-2 noise recorder at different stations in the world and together with some other data, the CCIR[8] have provided noise data on a worldwide basis in their report No. 322. Primarily, these estimates are related to the world distribution of thunderstorm days.

For presenting the data, the year has been divided into four seasons, viz. March-May, June-August, September-November and December-February. Each day has been divided into 6 four-hour time periods, viz. 00-04 hrs LMT, 04-08 hrs LMT,

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and so on. The aggregate of the corresponding one four-hour time period of the day throughout a season constitutes a time block. Actual measurements carried out by the different administrations in India show that the noise values as furnished by the CCIR are low in several cases and do not generally correspond to the actualities of the situation. The CCIR data do not adequately take into account the effect of local sources which are extremely important for India. The ARN-2 recorder has a limited dynamic range.

The CCIR, however, proposes to prepare a comprehensive revision of report No. 322 with due consideration to the alternative methods of presentation of the data[9].

3. Sources of the Noise

Every lightning flash can give rise to a noise burst. As is now known, lightning flashes are of different types. There are lightning flashes in which the electrical discharge strikes the ground (ground flashes), those in which the discharge occurs within the cloud only (cloud flashes) and those occurring between the cloud and the air. But, in all types of flashes, there are electrical discharges occurring inside the cloud. It is now known that these discharges inside the cloud are responsible for the radiations giving rise to a noise burst at any frequency in the lf, mf, hf and vhf bands. Ordinarily, in tropical latitudes, the cloud base is at a height of about 3 km above the mean sea-level. Radiations from discharges within the cloud can be received up to a distance of about 300 km by the direct ray. Hence, all sources lying within a distance of 300 km from the point of observation are called local sources. The days of a season on which such local sources are present are called days of local activity. Experimental investigations have shown that the number of days of local activity is approximately three times the number of thunderstorm days as recorded by the weather offices. Obviously, local sources are responsible for the highest amplitude noise bursts.

Sources lying between 300 and 1000 km are called near sources. Radiations from such sources in the mf and hf bands should ordinarily be expected to be received via the ionosphere. Consequently, the reception of radiations from such near sources depends on propagation conditions via the ionosphere and such reception may not be possible during certain hours of day at certain frequencies. Sources lying beyond 1000 km are called distant sources. Whenever propagation conditions at any given frequency are favourable, the signal from such sources can appear as noise in the receiver. It is expected that there can be a very large number of sources lying beyond 1000 km. Hence, a very large number of noise bursts of varying amplitudes should be received from different sources. It follows, therefore, that the noise arising from such sources would correspond practically to continuous noise. The noise arising from local sources is always in the form of distinct and well-separated noise bursts. The noise arising from near sources is mostly in the form of distinct noise bursts. But, when there is a number of near sources active, the number of noise bursts received per minute may be very large. This may give rise to noise which is almost of the continuous form.

4. Forms and Characteristics of Radio Noise

4.1 *Forms of Noise*

Noise, as understood today, is a complex phenomenon. There is what is called fluctuation noise and this does arise from several known factors either in the equipment or in the channel. Mathematical models for the treatment of this noise are already available. The second form of noise, known as 'impulsive noise', appears intermittently at random intervals and for random durations. The median value of the duration is defined in relation to the service for which the word 'impulse' is used. Thus, for voice communication, the ear can detect an impulse when it lasts about a millisecond. Therefore, noise of millisecond duration would be impulsive. Similarly, the ear gets the impression of continuous noise when the noise lasts for more than 200 milliseconds. But, the problem is slightly different in data communication. Suppose the bit that is transmitted is of 1 μsec duration. Then, anything that lasts about a microsecond would be an impulse for this purpose. It will thus be seen that the definition of an impulse is *relative* to the type of transmission of the signal that is envisaged. Since generalizations of impulsive noise are misleading without the appreciation of this crucial distinction, it is being stressed here. Even impulsive noise is a random process. The amplitude, the duration and the time interval between impulses vary in a random way. The problem with which an engineer is most concerned is to find out how a particular impulsive noise conforms within limits of error to one or other known forms of statistical distribution.

In some cases, noise lasts for an extended period of the time corresponding to many times the duration of an impulse as understood for a particular service. But, after the appearance of the noise for such an extended period, there is a pause when there is no noise. Thereafter, the same process repeats itself. In such a case, the problem posed is one of noise bursts. The duration and the time interval between such noise bursts are random variables and the types of distribution they follow need examination. The amplitude is a parameter difficult to define for a noise burst as a whole; but it can be done in various ways. First, one can think of the average or rms value of the envelope voltage in a noise burst. This approach is very satisfactory when the noise in the burst corresponds to fluctuation noise. One can also think of the integrated effect of the noise in the burst which would affect a particular type of service. In such a case, there would be what is called a 'quasi-peak amplitude'. This quasi-peak amplitude and the manner in which it has to be measured (and studied) would vary from service to service. Thus, in voice communication, the charging and discharging time constants of the equivalent electrical circuit of the ear become important. In some forms of data communication, the bandwidth employed limits the frequencies in the pulse and hence would indirectly give the time over which the primary pulses in the noise will have to be integrated.

Within a noise burst itself, there can be a number of quasi-peak amplitudes as described above, specially from the standpoint of data communication. Consequently, it is to be expected that they follow a certain distribution as far as their amplitude and time characteristics are concerned. Information on this point is vital for high reliability data communication. This, therefore, poses the need for double statistics. Thus, there is the need for the amplitude and the time statistics of noise bursts in their entirety. This may be called the macroscopic problem. Then, there is the need for the amplitude and time characteristics of the peak amplitudes or the impulses within a noise burst. Such peak amplitudes within a noise burst give rise to a variety of complications. First, the duration of a noise burst may be many times the duration of the bit that is transmitted. In such a case, there would be clusters of errors arising out of one noise burst. In optimal design, it is necessary to reduce the number of errors in such clusters of errors.

4.2 *Classification and Measurement of Atmospheric Radio Noise*

Extensive investigations carried out over a period of a decade revealed that atmospheric radio noise generally appears in the form of a continuous background over which are superposed distinct noise bursts. Further studies of the noise revealed that it is possible to classify atmospheric radio noise into three types[10,11]:

Type A: Low amplitude continuous noise. This arises principally from distant sources.

Type B: This is a burst form of the noise. In this case, the bursts as heard are not very sharp. The number of bursts received per minute is ordinarily 20/min, correct to a factor of two either way. This burst form of the noise generally arises from near sources.

Type C: This is also a burst form of noise. The bursts are ordinarily of shorter duration and the amplitudes are high. Noise in this form has been invariably traced to local sources. The number of bursts received per minute can vary over a wide range from a few to more than 40.

Over the entire mf and hf band, the magnitude of type A noise is of about the same order or even less than the other sources of interference taken together. It is difficult to separate out this form of the noise and carry out precise measurements. Experience has shown that it is more practical to lump this noise with other interference and state the level of the background.

Ordinarily, for the major portion of the time, atmospheric noise received in tropical regions consists mostly of noise bursts. Therefore, it becomes necessary to study the distribution of the duration and the time interval between such noise bursts. It is also necessary to study an amplitude parameter, which can be associated with a noise burst, as also the structure of a noise burst.

Over a short period of time, say 5 min, engineers expect at least 90% of the time satisfactory service. Therefore, the highest amplitude noise that is present for 10% of the time is the one of real significance. Consequently, highest amplitude noise bursts occupying 10% of the time have to be studied and their distributions generalized. Such amplitude studies are called 'short-term characteristics'. The median value of the amplitude for such a short term can be studied at the chosen hour over all the days of the season. This will furnish the required long-term characteristics. The long-term median value of the amplitude can be plotted against the hour of the day for the 24 hours of the day. If this graph shows an hour-to-hour change in the same direction for several hours, then during those hours, there is a systematic variation. This can arise from a variety of causes, viz. growth and decay of thunderstorms, changes in the condition of propagation, etc.

The common international practice is to lump four hours of the day together and divide the day into 6 four-hour time blocks as mentioned earlier. Noise data on a seasonal basis are furnished for each time block. The same practice can be followed for the furnishing of noise data on the basis of studies of noise bursts.

Studies on the time characteristics of noise bursts pertain to a study of the duration of a noise burst and the time interval between such noise bursts. Such studies are obviously carried out over a short period of time, e.g. 5 min. The study of the structure of a noise burst is primarily concerned with the peak amplitude pulses of a certain duration within the noise burst. What is significant is the distribution of the amplitudes of such pulses, their duration and the time interval between them.

When studies on the lines indicated above are carried out, one is studying basically the noise burst which arises from a lightning flash and is, therefore, a natural unit for dealing with atmospheric radio noise.

All such studies posed a variety of problems for instrumentation. These were tackled during different stages of the investigations. An integrated account of the instruments required and developed is furnished in the next section.

5. Instrumentation

5.1 *Quasi-peak Meter*

This method[12] was specifically developed for measuring the interfering effect of atmospheric noise to listening where the ultimate judge is the human ear. Extensive measurements have been made at Poona and Bangalore, based on this method.

The noise meter essentially consists of an aerial system, a communications receiver and a noise output meter which is fed from the output of the detector in the receiver. The output meter consists of a semi-logarithmic amplifier and a detector unit with a charging time constant of 10 msec and a discharging time constant of 500 msec. The time constants have been selected after extensive trial and error experiments in such a way that the output unit has characteristics very similar to those of average human ear. A microammeter is used in the discharging path for recording purposes. The frequency response of the output unit is flat within the frequency range 100-5000 Hz. The signal to be used for calibrating the noise meter is a sine wave modulated by a 400 Hz note to a level of 100%.

This method of measurement gives the quasi-peak value of the individual audible noise bursts in the form of kicks in the microammeter of the output unit and the average value of the envelope voltage in the form of a steady reading of the meter for the continuous background noise. Continuous aural monitoring becomes necessary to avoid the recording of man-made noise and station interference. The sensitivity of the receiver used in the noise meter can be changed in steps of 6 dB, with about 20 dB amplitude range in each position. This can suitably cover the amplitudes arising from a single frontal storm which have been observed to lie in a range of 20 dB.

By subjective experiments, a criterion which suitably takes into account the annoyance felt by the ear due to the bursts has been developed. According to this criterion, the annoyance is felt only when there are at least 10 bursts/min. By extensive investigations on the time characteristics of noise bursts, it has been found that the median value of noise burst duration is about 500 msec. Hence, ten bursts per minute occupy roughly 10% of time. Thus, Aiya's annoyance criterion refers to 90% of time intelligibility. The arithmetical average of the quasi-peak values of ten highest noise bursts received per minute over a short period of 5 min represents the annoyance felt by the ear and is termed as 'the noise burst level'. The mean value of noise burst field strength is most frequently found to be about 3 dB below the 'noise burst level' defined above.

5.2 *Peak Meter*

The peak amplitude corresponds to the highest pulse amplitude occurring in a noise burst and is necessary for the design of data communication systems. Optimal design of high reliability data communication systems requires also the number of peaks in a noise burst and their time functions which are discussed in a subsequent section.

This peak amplitude is measured by feeding the output of the last intermediate frequency stage of the receiver to an output unit having charge and discharge time constants of 1 and 160 msec respectively[13]. This unit is calibrated by using continuous wave signals and taking their peak amplitude.

5.3 *Average and rms Meters*

The average and rms values of the amplitude of a noise burst are required for deducing the continuous noise equivalent for being used in the design of data communication system. These values are measured by feeding the output of the last intermediate-frequency stage of the receiver to output units with charge and discharge time constants of 170 and 500 msec respectively for the average value, and of 80 and 500 msec respectively for the rms value[14]. They are calibrated by using the peak carrier values of continuous signals modulated 100% by a sinusoidal tone of 400 Hz.

5.4 *Vhf Peak Meter*

An instrument for the measurement of vhf atmospherics was set up consisting of essentially a dipole antenna, a balun to match the antenna to the coaxial feeder, a vhf receiver tuned to 63·5 MHz with a pass band of 5 MHz and an output unit[15]. The output unit had been designed to measure the peak field strength of vhf atmospherics as the dial reading of a microammeter.

5.5 *Lightning Flash Counters*

Radiation field-actuated, lightning flash counters operating at 1·6 and 3 MHz with different thresholds were constructed[16] and used extensively in studies on noise burst rates and characteristics of thunderstorms. A simple, cheap, portable and reliable instrument for the collection of data on the number of lightning flashes of all types per unit time over unit area of the earth's surface, called lightning flash density gauge, was recently fabricated and used to record flash densities[17].

5.6 *Pulse Rate Counter*

A pulse rate counter has been developed to count the number of pulses in a noise burst crossing a certain amplitude threshold and simultaneously to record the burst duration corresponding to the pulses. The instrument has been designed[18] to receive noise pulses at 3 MHz with a bandwidth of 3·3 kHz/6 dB.

5.7 *Atmospheric Noise Burst Generator*

This instrument[19] employs Zener diodes and gas tubes as sources of noise and multivibrators for the simulation of pulses in the atmospheric noise bursts. The artificial noise bursts generated using this instrument exhibit all the observed characteristics of natural noise bursts over the frequency range 0·1-10 MHz.

6. Noise Bursts

In this section, the results of various studies conducted on noise bursts using the instruments described in section 5 are discussed.

6.1 *Amplitude Parameters*

6.1.1 *Lf measurements* — Quasi-peak levels of noise bursts were measured at Bangalore at 105 and 280 kHz with a receiver bandwidth of 4 kHz/6 dB. The distribution of these values has been extensively investigated over 'short terms', i.e. periods of 5 min at different hours of the day and on different days of the seasons, and was found to be log-normal with a standard deviation of about 4 dB. The mean value is generally found to be about 3 dB below the noise burst level. The long-term characteristics of noise burst levels, obtained from the short-term values for a selected half hour of all the days of a season, indicate systematic variation in certain time blocks[20].

Quasi-peak and peak values of noise bursts were measured at Bangalore at 30 and 60 kHz also[21]. There is a broad agreement between the peak values obtained in the measurements and those given by CCIR.

6.1.2 *Mf and hf measurements* — Extensive measurements were made in mf and hf bands that formed later the basis to provide data in these bands. Investigations on atmospheric noise interference were conducted at Poona in both the bands and measurements were made at several spot frequencies[22-27]. The short-term and long-term distributions of quasi-peak values of the noise were studied at 3·0 and 4·5 MHz within a bandwidth of 6 kHz/6 dB at Bangalore[28-30]. A study of the characteristics of the noise in the 1·5-3·0 MHz band revealed that the noise levels show systematic variation between 12-20 hrs IST, while the distribution for the time block 12-16 hrs can be represented by a single log-normal distribution; for the time blocks 16-20 and 20-24 hrs they are heterogeneous[31]. Good correlation was observed between half-hourly noise burst levels at 1·6 and 2·9 MHz and it was found that noise level at one frequency can be predicted from that at another with a standard error estimate of about 3 dB. However, the correlation decreases as the frequency separation increases[32]. Measurements were made to investigate the effect of receiver bandwidth on the quasi-peak values and time parameters of noise bursts in the frequency range 0·1-9 MHz[33]. The quasi-peak value varies as the square root of bandwidth from 0·3 to 6 kHz. There is no effect on time parameters of the noise bursts and for both amplitude and time parameters, the distribution which is log-normal does not change with bandwidth, and the standard deviation is also unaffected.

By the simultaneous collection of data on noise bursts for the peak, average, or rms value and the quasi-peak value in a suitably randomized way at different frequencies and statistically analysing them, the ratio of each of the different parameters to the quasi-peak value was determined[13,14]. In this way the most appropriate conversion factors for different frequency ranges for all the three amplitude parameters were evaluated.

Peak and quasi-peak values were also measured simultaneously for the same noise burst using calibrated cathode ray oscillograph (CRO) and noise meter, at 3 MHz with 3 kHz/6 dB bandwidth. The ratio of both the values was in broad agreement with the earlier measurements[13], but was found to increase by about 3 dB for 8 kHz/6 dB bandwidth at the same frequency[34].

6.1.3 *Vhf measurements* — Atmospheric radio noise in the vhf band received practically no attention at high latitude regions possibly due to the presence of a high level man-made noise. CCIR report No. 322[8] also does not furnish information in this band. The noise, however, assumes importance in countries in the tropical region due to the intense activity of thunderstorms and existence of low man-made noise because of the relatively underdeveloped nature of these countries.

In view of this, measurements were made at Bangalore, on the frequency of occurrence and the magnitude of the noise in its continuous and burst forms at 63·5 MHz in a pass band of 5 MHz/3 dB, and data were furnished[35,36]. The data provide, for the first time, useful guidelines on which assessment of atmospheric noise can be made for use in planning vhf communication and radio-astronomy systems.

6.2 *Time Parameters*

The time parameters of relevance in the study of noise bursts are the burst duration and the burst repetition rate. The interval between the time when a burst becomes audible to the time when it becomes inaudible represents the burst duration. The number of bursts received per minute represents the burst rate. Tape recorders and level recorders have been employed in the study of time parameters. Such measurements covered a wide range of frequencies from lf to hf bands and measurements were carried out over long periods of time.

It has been found that both these parameters are random and follow a log-normal law. The median duration of noise bursts has been estimated to be about 500 msec with a standard deviation of 6 dB[37]. When the activity of a thundercloud is around its peak, the mean value of the duration of a burst has been observed to be about 200 msec. At other times it is larger[38,39]. The mean duration of a noise burst is observed to exhibit a systematic variation with the growth and decay of the activity of a thundercloud, and found to follow the cyclic variation corresponding to the growth and decay of cells in thunderclouds[40].

The burst duration measurements carried out using the pulse rate counter give a median value of about 200 msec and a standard deviation of 6 dB[41]. Since the measurements were carried out after slicing the burst at a certain amplitude level, the value of 200 msec for the burst duration corresponds to the peaks in the noise bursts. This confirms Aiya's observation[11] that the maximum amplitude changes, including the most violent of such changes, are confined to only about 0·2 sec part of the burst.

Apart from magnetic tape and level recorders, lightning flash counters and noise burst field strength meters also have been used in the study of the burst repetition rate, which is a direct index of the growth and decay of the activity of a thundercloud. In an active thundercloud, a decaying convection cell gives rise to a new cell and this process continues until the thundercloud itself decays. The growth and decay of cells thus produce a cyclic variation in the burst repetition rate. For the greater portion of the activity, the burst rate exceeds the value of 1 and often reaches the value of 40. The number of active cells recorded per thunderstorm has a mean value of 5 with a cell life of about 30 min[42,43]. However, the mean occupation time in per cent and noise burst rate were found to be highly correlated, despite the duration variation, thus allowing prediction of the former for a given noise burst rate[40].

Another parameter of interest in the study of time parameters of noise bursts is the burst repetition period. This refers to the time interval between successive bursts becoming audible. The magnetic tape recorder technique has been extended for the repetition period measurements. This parameter has also been found to follow a log-normal law in the lf, mf and hf bands. The median value has been estimated to be about 1·4 sec with a standard deviation of 4 dB[37].

6.3 *Structure of Noise Bursts*

6.3.1 *Primary pulses from lightning flashes* — Actual radiations from a lightning flash occur as a number of primary pulses of random amplitude, duration and time interval between two successive pulses. The duration of such pulses is of the order of microseconds or very much less. Occasionally such pulses occur in bunches for periods of a millisecond or less. It is such bunching which probably corresponds to the K-type of discharges, stepped leaders, etc. When such pulsive radiation passes through a receiver tuned to a spot frequency and bandwidth, the waveform gets modified. The bunched primary pulses get integrated because of the receiver bandwidth and become pulses of the order of milliseconds duration in the noise bursts. These pulses in noise bursts determine the clusters of errors in digital communication through the burst error channel.

6.3.2 *CRO studies* — CRO records of several noise bursts due to narrow band atmospherics were obtained using Tektronix oscilloscope type 545 and a qualitative study of waveform was carried out at several frequencies. A narrow band atmospheric is found to consist of several pulses of amplitude ranging from a few microvolts to tenths of a volt. The time of recurrence of the pulses and the total number of pulses appearing in a noise burst are random phenomena. At lf and below, the pulses appearing in a noise burst are few and have relatively large amplitudes. The principal source of vlf and lf emission from lightning flashes has been traced to return strokes in the ground flashes and K-type of discharges in cloud and air flashes. At mf and hf bands more pulses appear in a noise burst and correspondingly the peak amplitudes attained by these pulses decrease. The waveform of a typical noise burst[41], as recorded at 3 MHz with a receiver bandwidth of 3·3 kHz/6 dB on a CRO screen, is reproduced in Fig. 1. A study of these waveforms has shown that all types of flashes are equally effective in radiating noise pulses in the mf and hf bands. Collection of data on the number of pulses at a given frequency and bandwidth is of importance in predicting the performance of data communication systems.

Preliminary measurements on the number of pulses in a noise burst were carried out using a CRO[19]. However, counting of the exact number of pulses in a burst directly from the CRO records was found to be very difficult. Whenever several pulses occurred very closely in a burst, the overall trace appeared as a continuous patch and individual pulses could not be distinguished. Therefore, CRO records do not seem to be useful means of collecting such data in the mf and hf bands. High resolution pulse rate counters are well suited in counting the pulses in a burst over a specific threshold level.

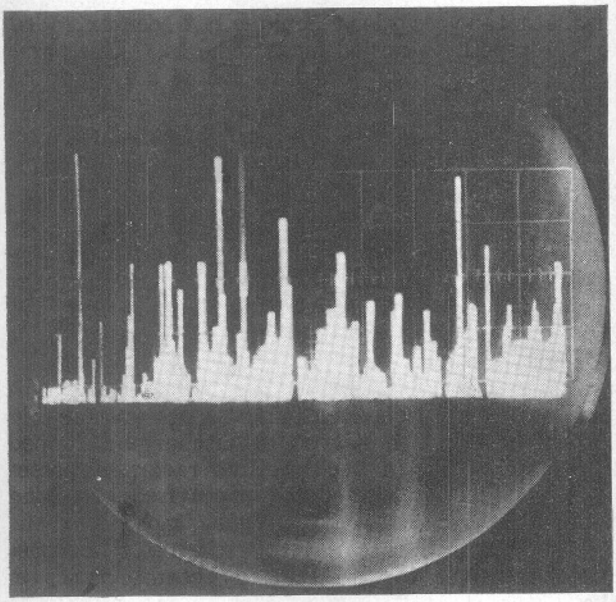

Fig. 1 — Oscillogram of a typical radio noise burst as recorded at 3 MHz with a receiver bandwidth of 3·3 kHz (on a time base, 50 msec/cm)

TABLE 1 — PULSE CHARACTERISTICS OF ATMOSPHERIC NOISE BURSTS AT 3 MHz WITH 3·3 kHz/6 dB PASS BAND

(Distribution of all parameters listed is log-normal)

Parameter	Median value	Standard deviation dB
No. of pulses in an amplitude range of 6 dB from the peak	20	9·0
Duration	200 msec	6·0
Pulse rate in noise bursts normalized to 100 msec	10	7·0
No. of pulses in an amplitude range of 12 dB from the peak	45	8·0
Duration	270 msec	6·0
Pulse rate in noise bursts normalized to 100 msec	17	6·5

6.3.3 *Pulse rate counter studies* — The pulse rate counter developed to count the number of pulses in a noise burst crossing a particular amplitude threshold and simultaneously to record the duration corresponding to these pulses was previously described[18,41]. The instrument has been used at Bangalore (12°58′N, 77°35′E) to investigate the pulse characteristics of noise bursts at 3 MHz with a receiver bandwidth of 3·3 kHz/6 dB.

The parameters of noise bursts studied were: (i) number of pulses, (ii) burst duration, and (iii) pulse rate normalized to 100 msec duration of the burst in an amplitude range of 6 and 12 dB from the peak value of the burst. All the three parameters are found to follow log-normal distribution rather than a Poisson distribution which would be expected for the random events. The corresponding median values and the standard deviations[41] are given in Table 1.

The results presented in Table 1 pertain to studies of locally active thunderclouds during their peak activity and the duration of a burst as mentioned corresponds to the time interval between the first and the last pulse of the magnitude indicated. There is always some noise in a burst before and after such pulses.

7. Results

The instruments described in section 5 were developed for specific purposes and were designed to realize the objective to the maximum possible extent. Their limitations, if any, have been discussed in the papers describing them and arise principally from the limitations of the available technology. Improvements should always be possible. In order to eliminate the effect of such limitations on the results and their interpretation, the maximum possible precautions were taken both in the design of the experiments and the interpretation of data.

Conclusions of significance arising out of the two decades of continued experimental work are of relevance to three major areas, viz. characteristics of the random processes, characteristics of tropical thunderstorms and characteristics of atmospheric radio noise over the land mass of India. In what follows, a brief summary of the results pertaining to each of these areas is furnished.

7.1 *Random Events*

The duration of a noise burst, the time interval between successive noise bursts, the amplitude of a noise burst, and the number of noise bursts received per minute at a certain frequency follow the log-normal distribution. The number of pulses within a certain range of amplitude in a noise burst and the time interval between successive pulses also follow the log-normal distribution.

The lifetime of a thundercloud, the lifetime of a convection cell in a thundercloud, the number of such cells developed during the lifetime of a thundercloud, the duration of a lightning flash, the time interval between successive flashes, the peak rate of flashing in a lightning discharge and the distance up to which thunder can be heard follow the log-normal distribution.

A Poisson distribution is a normal expectation for at least some of the random events. Therefore, the conclusions drawn have been carefully rechecked. The log-normal law is an approximate representation and not a perfectly accurate one. But, the accuracy realized is of the order of 90%. This should be deemed adequate for most engineering evaluations.

7.2 *Thunderstorms*

Some of the conclusions which follow from the current investigations on the characteristics of tropical thunderstorms have been described and discussed earlier[38,44]. During spring and autumn, storms develop, grow and decay ordinarily during the afternoons and last for 3-4 hr. But during the regular monsoon period, viz. summer, they are usually long drawn out. In any such typical thunderstorm over the land mass, it appears that several thunderclouds in the different regions of the large area involved become active but during different periods of the day. Consequently, there is activity from about local noon till the time of sunrise the following day. The decay in activity is rather sharp. Thunderstorm days occur in bunches, the most probable number being 4. Thunderstorms over the sea appear similar but for one distinct characteristic, viz. a peak of activity between 16 and 17 hrs LMT followed by a sharp fall immediately thereafter.

Recent round the clock studies of noise field strengths during local storms show a cyclic variation of this parameter and the measurements of the time interval between successive crests and troughs give a lifetime for a thundercloud which is about the same as that obtained by other methods[21]. This confirms the previous conclusion drawn indirectly that a thunderstorm activity as such arises from the activity of several thunderclouds.

The lifetime of a convection cell has a median value of about 30 min. This is the same as that reported from experiments in temperate regions. But, the median value of the number of such cells developing during the activity of a thundercloud is 5. The median duration of the life of an active thundercloud is about 3 hr. This is very much higher than the values reported from temperature regions. The distance probability distribution of thunder heard is log-normal with a median value of 9 km[15].

The following conclusions emerge regarding the lightning discharge. The lightning discharge is continuous throughout the activity of a thundercloud. But, the flashes occurring are of different types, the largest number being the cloud flashes, many of which cannot be seen by visual observation. Whenever thunder is heard, there are always some ground strokes. If seasonal averaging is done, it is found that about 10% of all the flashes are ground flashes[45]. This percentage is very small compared to the observed percentages in temperate regions. The median value of the peak rate of flashing during the activity of a thundercloud is 8/min. But, rates of flashing as high as over 40/min have been occasionally observed. The median value of the duration of a flash is 500 msec. However, this value gets reduced to about 200 msec during the peak activity of a thundercloud. The noise power radiated by a typical flash has been theoretically evaluated and the results compared with the measured median values. There is agreement between the two[15]. The noise field strength varies with the stage of activity of a thundercloud and becomes maximal when the activity has reached its peak[30]. The random variations of the integrated value of the radiation fields arising from a flash when measured at one predetermined distance lie within a range of 20 dB.

Within a flash, K-type discharges have been reported by workers investigating lightning discharge. These are found to correspond to the pulses within a noise burst which lie within 6 dB of the peak amplitude pulse[41].

7.3 *Noise Data for India*

In the frequency range 0·3-30 MHz, the noise data required for the different types of radio communication services have been furnished for the entire land mass of India[46,47]. This is done through a set of three data sheets and a map of India giving the days of local activity in the different regions during the four seasons of the year. The first sheet gives the data for voice communication. The second one gives the conversion of these data for data communication and the other details necessary. The third sheet furnishes the desirable signal-to-noise ratios. The procedure for arriving at the appropriate noise level for a desired percentage of time for ensuring satisfactory long-term service has been described and the required set of nomograms have been prepared[48]. The basic data are for a 1 kHz bandwidth at 1 MHz with the necessary conversion factors for other frequencies and bandwidths. Since the procedure adopted in the furnishing of these data is of scientific interest, it is described briefly in the next paragraph.

Communication engineers expect at least 90% of the time satisfactory service in a short period of time, say 5 min. Hence, the highest amplitude noise present for 10% of the time is measured and studied. The mean value of this noise as a source of interference to voice communication is called the noise level (N). It can be converted into rms, average, or peak amplitudes by the use of statistically assessed conversion factors. The short-term characteristic of N is log-normal and the median value and standard deviation are adequate. The distribution of the median value of N over a long period of time like a time block is also log-normal. Hence, long term characteristics are adequately represented by the median value and standard deviation. Data are furnished separately for days of local activity and for other days. For data communication, this information is supplemented with the data on the peak amplitude pulses in a noise burst.

Atmospheric noise in India as examined this way consists of noise bursts arising from the local or near sources. The distant sources and other interference contribute to a background which has been evaluated and furnished. A surprising result confirmed by actual experiments is the fact that there is no atmospheric noise during the hours 08-12 hrs LMT. Similarly, on days other than the days of local activity, there is no atmospheric noise during 12-16 hrs LMT.

For the vhf band, 30-300 MHz, atmospheric noise data[15] are furnished at 100 MHz and a pass band of 1 kHz. Values for other frequencies and bandwidths can be deduced by applying the inverse frequency and the square-root bandwidth laws. The rms value of the equivalent fluctuation noise at 100 MHz and 1 kHz pass band, present for 10% of the time, for about an hour at a time at least once on a thunderstorm day between local noon and midnight is 20 ± 10 dB above 1 μV/m.

Vhf noise radiation from lightning flashes can travel to distances of the order of 500 km via the sporadic E-layer or by troposcatter. This is estimated to give rise to continuous noise of the order of 0·1 μV/m at 100 MHz and 1 kHz pass band. This noise will be present even in remote places during the thunderstorm seasons and has to be reckoned with in the planning of radio-astronomy work.

8. Conclusion

The lightning flash is the source of atmospheric radio noise. The geographical location of the land mass of India makes it one of the most suitable countries in the world for scientific studies of atmospheric noise in terms of the lightning flash. Such studies over a period of over two decades have furnished a wealth of valuable information. They have enabled the furnishing of noise data in a simplified but rational way. They have led to results of value on thunderstorms and lightning. A judicious use of the instruments developed can lead to the collection of further valuable information on thunderstorms and lightning.

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