THE INTERFERENCE ENVIRONMENT OF RADIO NOISE FROM LIGHTNING

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ABSTRACT

The paper furnishes a review and an overview of radio noise from lightning as a source of interference to analogue and digital Communication. The parameters of the different forms of noise necessary for assessing the interfering effect of the noise are described. Available information on thunderstorms, thunder-clouds, convection cells and lightning are reviewed and their limitations pointed out. There follows a description of how the source, propagation and receiver characteristics determine the structure of atmospheric noise as received at a point of observation. The natural unit for this noise is the noise burst arising from one complete lightning flash. The parameters of the noise burst as a whole and its structure determine the interference environment. A historic review of atmsopheric noise studies shows that it is currently of importance only in the tropical regions of the world for which the available data are very defective. New data are furnished. The contribution of atmospheric noise for background interference even in remote places for radio astronomy at VHF is furnished. The importance of atmospheric noise occurring sporadically in high values for short intervals at VHF and higher frequencies in the tropics is brought out.

Key words: Thunderstorms, thunderclouds, convection cells, lightning, noise, interference atmospheric noise and its data.

1. INTRODUCTION

The engineering of radio communication involves the design and development of a complete system to meet a communication need. Optimal design as visualized to-day envisages the transmission of the maximum amount of information with a stipulated degree of reliability within a set time by using the minimum amount of radiated power. This requires a knowledge of the interference environment in much more precise terms than

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before. Noise arising from different sources are important components of this environment. Noise arising from sources within the receiving system called internal noise can be correctly evaluated and it is possible to engineer its reduction. Noise arising from sources outside the receiving system can be either extra-terrestrial or terrestrial. Such noise corrupt the signal before it enters the receiving system. The magnitude of any parameter of such noise which arises from natural phenomena is not controllable. While dealing with it in statistical terms, the important consideration is to identify the statistical law it follows to the order of accuracy required. External noise can, to some extent, be reduced through directional reception.

Atmospheric radio noise is external noise of terrestrial origin. It is traced to the electrical discharges accompanying lightning flashes in thunderstorms. The electromangetic radiation arising from such discharges covers the entire frequency spectrum. The power radiated by the source at a given frequency and within a defined bandwidth is different at different frequencies. The frequency range over which it is received from a particular source at a specified receiving point is determined by the laws of propagation. The characteristics of atmospheric noise are known to vary with frequency, geographical location, time of day, season, etc.

Studies of atmospheric noise have been emphasised and de-emphasised during the last five decades. Such studies have often been limited to frequency bands of interest to system designers at a given point of time. The scope of such studies has been restricted to getting quick results for meeting the immediate requirements of system designers. Sporadic but severe interference arising from this noise has received scant attention. But, this type of interference can be of some significance to different types of communication in the VHF, UHF and SHF bands and to radio-astronomy and space communication. Source characteristics, the amplitude and time parameters of the noise necessary for assessing its interfering effect, etc., continue to be problems needing universally accepted conclusions. It is against this background that this paper attempts to present an overview and review of the subject keeping in view the possible needs of the future.

The section headings indicate the scope of the paper.

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The choice of material, organization of the subject matter into the indicated order of presentation and emphasis in the treatment are those of the author. A signal process corrupted by additive white noise has been extensively investigated [179]. Could the importance of other forms of noise be brought out and the necessary information on them furnished to stimulate investigations or should one rest content with approximating all forms of noise to additive white noise is a big question ? An attempt is made to pose the question in this paper.

2. NOISE [1–9]

Noise is a disturbance which comes in the way of recovery of information contained in a transmitted signal. The parameters of noise necessary for assessing this interfering effect may not be the same for all types of services. If the parameters necessary for different purposes are different, an attempt has to be made to find a relationship between them either theoretically or experimentally. The characteristic of a chosen parameter may vary over a wide range from a highly regular to a completely random one.

2·1. *Forms of Noise*

One form of noise is continuous noise or fluctuation noise. For such noise, the power spectrum is continuous and uniform. This implies that the power in a particular frequency interval is proportional to that interval. Hence, it is often called white noise although it is known that the power spectrum of 'white light' is non-uniform. Continuous noise possesses an envelope and the rms value indicates the power involved. Its instantaneous amplitudes are distributed according to a normal distribution of errors. When this noise is fed to a linear detector, the instantaneous voltages at the output follow a Raleigh distribution.

When noise appears at intervals and is of short duration compared to the interval, it is called impulsive noise. Ordinarily, both the duration of the noise and the time interval between its occurrences are random processes. The duration of an impulse has to be 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. Hence, noise of millisecond duration is impulsive for voice communication. The ear gets the impression of continuous noise when the noise lasts for more than 200 milliseconds. The problem can be different for data communication. Suppose the bit that is transmitted is of one mirosecond duration. Then, anything that lasts for a microsecond may have to be regarded as an impulse. Therefore, the definition of an impulse has to be in relation to the type of transmission envisaged. Impulsive noise has both amplitude and time characteristics.

In some cases, noise lasts for an extended period of time corresponding to many times the duration of an impulse as visualized 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. When noise appears this way, it is said to appear in the form of noise bursts. The noise bursts in their entirety will have both amplitude and time characteristics These represent the macro-structure of noise bursts. Within a noise burst itself, there can be a number of impulses and these will have both amplitude and time characteristics and these may be looked upon as the micro-structure of noise bursts. Information on both the macro and micro structure of noise bursts are necessary for modern communication.

In practical situations, it is possible to have impulses or noise bursts superposed on continuous noise. Mechanically lumping all of them together may furnish an incorrect picture of the actual interference environment. Therefore, criteria have to be established either for ignoring one or more of them or for lumping them together. Occasionally, there are situations in which each form of noise arises from more than one set of sources.

2·2. *Parameters of noise*

Continuous noise has been extensively investigated both theoretically and experimentally. It arises from the superposition of a large number of random events which, for purposes of a service, are not required to be sepaately distinguishable. The relatioship between peak, rms, and average amplitudes are well understood. Its amplitude is best specified by an rms value.

Impulsive noise and noise bursts have both amplitude and time parameters. A noise burst may consist of a continuous background on which are superposed a large number of impulses. An impulse could be made up of a large number of primary pulses. The duration of a noise burst could be approximately taken as the time interval between the first and last impulses in the noise burst. The duration of an impulse could be taken as the time interval between the first and last pulse in an impulse. In practice, these get indirectly specified by the circuit characteristics of the recording gear. The time interval between two successive noise bursts is the time between the last impulse of one noise burst and the first impulse of the next. A similar definition is valid for the time interval between impulses.

For the amplitude, one could think in terms of the average value of the envelope voltage in a noise burst or in an impulse. This approach is very satisfactory when the impulses in a burst or pulses in an impulse are very large and their amplitudes are not significantly different from that of a possible continuous background, if any. Another approach is to think in terms of the integrated effect of the noise in a noise burst or in an impulse which would affect a particular class of service. In such a case, there would be a quasi-peak value of the amplitude.

2·3. *Characteristics of Noise*

By studying a parameter of noise over a short period of time, it is possible to deduce its characteristics. These are called 'short term characteristics'. There is no rigorous or accepted definition of 'short term'. Ordinarily, the characteristics of a parameter of noise do not change noticeably within about five minutes. Hence, there is, at present, no objection to regard five minutes as a short term. When the parameter is a completely random event, it is possible to furnish its median value and standard deviation. These will be called 'short term values'. In this connection, it is pertinent to point out that, in some cases, *viz.*, atmospheric noise bursts, studies will get restricted to a very limited population, often less than 100. This can limit the accuracy of evaluations. It is possible to improve the accuracy by repeat studies. For some parameters of some types of noise, all that is required is just these short term characteristics.

By studying the variation of the 'short term values' at the same hour over all the days of a month, a season or a year, one can obtain the 'long term characteristics'. Usually, a season is regarded as adequate for purposes of the term, 'long term'. In some cases, it becomes necessary to group days separately as days of low and high noise in the season and then deduce data. Such situations have arisen in the case of atmospheric noise.

Due to variations in natural phenomena, it may be observed that there is a systematic variation on a long term basis from hour to hour of a certain parameter like amplitude. In such cases, for the hours concerned, it may be necessary to give the variation of the long term hourly values.

At VHF, UHF and SHF, noise of significance may appear sporadically. This is particularly so when radiations from lightning are within the cone of reception be it at ground or in space. In such cases, in addition to the values of the parameters, it is necessary to state the median duration of this sporadic outburst and, where possible, the most probable hours of day and seasons when this can be expected.

Lumping all short term data and then deducing long term characteristics is not desirable as this may result in erroneous information. Differences between prediction and actual observation can, not infrequently, be traced to such procedures.

2·4. *Noise Data*

Noise data have to be furnished in terms of the appropriate noise parameters and must include ' short term ', ' long term ', and systematic variation characteristics. Sporadic occurrences must figure quite appropriately. They are likely to be of increasing utility value in the future. In order to assist the system designer to appreciate properly the interference environment, it is necessary to furnish the data in sufficient detail and with the required stress on the limitations of the data. Over-simplification and uncalled for generalizations are not likely to serve any useful purpose.

Very long term variations like those over a sunspot cycle, etc., are relevant but one is not sure whether the stage is reached for furnishing data of a reliable character.

3. Sources of Atmospheric Noise [10–22, 50–54, 56, 60, 61, 72, 76, 79–82, 91, 92, 100, 105, 106, 109, 110, 121, 125, 126, 128, 134–139, 143, 144, 146–148, 152, 155–157, 176, 177, 180, 182–186, 188, 192–200, 205–207, 213, 217–223, 228–232, 237–240, 248, 251, 253, 257, 259, 261, 266–269, 271, 276–281, 287–292, 297–302].

The characteristics of atmospheric noise as received at a point of observation are determined almost entirely by the characteristics of its sources and the laws of propagation. The limitations imposed on our knowledge of the noise arise from the limitations of our knowledge about the sources and the laws of propagation. Further, several of the differences between the predicted and observed characteristics of the noise and the anomalies reported can only be understood by knowing the source characteristics and the laws of propagation. Looking ahead, sporadic appearance of atmospheric noise of high intensity in VHF, UHF and SHF communication can only be predicted properly on the basis of a knowledge of the sources. Therefore, this source problem is being dealt with at the very outset.

It is known that a thunderstorm is a localized thermodynamic process in the atmosphere accompanied by electrical discharges. The acoustical shock wave produced by the discharge is thunder and the visible electromagnetic radiation is lightning. There are reference to thunder and lightning in ancient literature like the Rig Veda of India. In the eighteenth century, D'Alibard in France and Benjamin Franklin in the USA showed that lightning is electrical in nature. Popov utilized the radiations from lightning to demonstrate radio reception towards the close of the last century. Appleton, Chapman, Watson-Watt, Schonland, Norinder, Lutkin, McEachron, Malan, Mason and a host of others have made valuable contributions to our understanding of lightning problems. Yet, much remains to be done.

The principal source of atmospheric noise is the lighting flash and the radiation arising from it is called an atmospheric. These lightning flashes occur in active thunderclouds which exist in thunderstorms. In what follows, the available information of relevance to the subject of discussion is summarized pointing out possible gaps in knowledge which have to be filled.

3·1. *Thunderstorm Days*

A thunderstorm day is a Calendar day on which thunder is heard.

Weather offices throughout the world are logging the dates on which thunder is heard. The data so collected is analysed at the national and international levels. This data is basic data which has to be utilized judiciously for deducing the characteristics of atmospheric noise, particularly in regions where no measurements have been made.

The available data has its limitations. Some countries had and have a large network of stations for recording this data but, in many others, the number of stations is limited. For some places, the data exists for decades but, for others, it may be over a short period or intermittent. For sea masses, the data is extremely poor, The distance upto which thunder can be heard depends on wind direction and velocity, acoustical noise level, the observer and the general meteorological conditions. The effect of all these can disappear when the data for analysis is large. Unfortunately, this is not always so. Besides there can be lightning without thunder and this goes unrecorded.

Even if thunder is heard continuously more than once in a day, there is no indication of this in the data. No information can be obtained about the severity of the activity. Ordinarily, the distance upto which thunder can be heard is taken as about 10 km or 6 miles. A detailed investigation carried out in Bangalore in which over 1200 cases were logged showed that the thunder heard distance distribution is log-normal with a median value of 9 kms. Ordinarily, thunder heard is taken to indicate an actvity over an area of 1000 kms. This is reasonably correct as the area involved in the activity of thundercloud approximates to a circle of radius between 10 and 20 kms.

The data on thunderstorm days has been analysed. Brooks has furnished the data through lines of equal frequen y of thunder, *viz.*, isobrants, for April–September, October–March and the whole year on global maps. Aiya has furnished the thunderstorm days data for India for regions lying within five degrees of latitude and longitude. The World Meteorological Organization has published the world distribution of thunderstorm days in the form of tables and charts.

3.2. *Thunderclouds*

A sequential series of processes culminating in the lightning discharge and sustaining this discharge over a period of time are confined to a single cloud in a storm. This cloud in which the electrical activity occurs is the 'Thundercloud'. If the activity is idealized to occur in a circular area, the radius of the thunder cloud ordinarily lies between 10 and 20 kms. The base of this thundercloud is about 3 kms. above mean sea level (MSL) in the tropics but this height has a lower value in temperate regions because of differences in the height of the tropopause. The thundercloud top is generally ill-defined but can be as high as 14 Km. Radiation from the electrical activity inside the cloud can be expected to follow the line of sight propagation upto distances of the order of 300 kms. Within this thundercloud, the temperature can vary from about 8°C to less than (—20°C). There is thus a wide temperature variation from the bottom to the top of the thundercloud.

The thundercloud as described consists of a number of thundercloud cells. These cells are interlinked by inactive and non-turbulent cloud material. On an average, there are five such cells in a thundercloud in the tropics. In temperate regions, the number of such cells is much less and can be just one or two.

The current view on thundercloud electrification could be put as follows There is a wide difference in temperature and pressure along the vertical length of the cloud. This can give rise to intense updrafts inside the cloud. These can get intensified when warm air moves upwards from the surface of the earth towards the cloud. The updrafts carry alongwith them water droplets which are thrown against ice crystals found at higher levels inside the cloud. The water droplets when they come into contact with ice crystals freeze on the surface. This leads to splintering. Because of unequal rates of diffusion of hydrogen and hydroxyl ions in water droplets along the radial temperature gradient, the splinters acquire an excess of positive charge whereas the remaining heavier portion becomes negative. The updraft blows up these positively charged ice splinters towards the top of the cloud and under dynamic balance of gravity and the updraft, the heavier negative charge carriers fall towards the base of the cloud. A high potential difference thus develops between the top and bottom of the cloud. (There is a small amount of positive charge at the base of the cloud but this is not clearly understood.)

When the high potential difference created exceeds the disruptive strength of the dielectric, a discharge occurs and lightning activity commences. The thundercloud becomes electrically active. The development of electrical activity in a thundercloud is a random event. Therefore, there is, *a priori*, no reason to doubt more than one thundercloud becoming active at different times or even simultaneously in a thunderstorm whose activity is spread over a much wider area than that of a thundercloud.

The median value of the duration of the activity of a thundercloud in the tropics lies between three and four hours. The median value of the life time of a thundercloud cell lies between 30 and 40 minutes. The duration of peak activity, *i.e.*, the time during which the rate of flashing is above half the peak rate of flashing is about 10 min. The growth of activity is rather gradual but the decay is sharp.

3.3. *Thunderstorms*

The word, 'thunderstorm', as ordinarily used stands for several phenomena like strong gusty winds, vertical currents of air at higher altitudes, heavy precipitation, and, thunder and lightning taken together. Such storms occur all over the globe and are due to the rapid movement of air in the atmosphere due to differences in pressure, temperature, etc. The more violent of these storms are often referred to as cyclones, typhoons, hurricanes, tornadoes, etc. Thunderclouds develop and become active only in such storms.

Broadly, there are two types of storms, *viz.*, convective or local storms and frontal storms. Convection currents in air due to the heating of the surface layers of air are responsible for convective or local storms in which cloud formation, etc., result. The area involved in the activity of such local storms is usually small. It may correspond to the area involved in a single thundercloud activity or of that order. The activity of such storms is ordinarily restricted to a few hours between local noon and local sunset in the tropics. There is the possibility of such isolated local storms occurring in several adjoining areas near a place of observation. At such a place, each such storm gets recorded by the thunder heard and a record may indicate a day as a day of two or even three storms. A significant proportion of storms in tropical India belong to this category during March–May and September–November.

Cooling of humid air and formation of clouds can also be brought about by frontal lifting. Thus, when two fronts, a cold one and a warm one meet each other, the warm front surmounts the cold front and is given an upward thrust. The air may cool and, if there is enough moisture, variety of clouds may be formed and the development of thunderstorms may occur. Such storms are called frontal storms. They can occur at any time, either on land or on sea. They persist for a long time. There can be thunderstorms due to a combination of causes responsible for local and frontal storms. Frontal storms extend over very large areas.

There is indirect evidence that the storm days at a place in the tropics bunch together with a most probable value of four.

Thunderstorm days data does not distinguish between local and frontal storms. By judicious experiments, it is necessary to get to a formula for finding the relative percentages of the two types of storms. This percentage obviously will vary from place to place. Similarly, a severity index as suggested by Forrest is necessary for finding out the number of severe storms.

3.4. *The Lightning Discharge*

As a result of separation and accumulation of charges in thunder-clouds, high potential gradients are developed. When the field at any point exceeds the breadkdown strength of the medium, a discharge is initiated and this is the 'lightning discharge'. As visually observed, lightning consists of a series of intermittent visible radiation described as flashes. When such flashes occur within the cloud only, they cannot be seen. The visible radiation is only a part of the radiation from a lightning flash. The entire electromagnetic spectrum appears to get covered by radiations from lightning flashes. This is the principal source of atmospheric noise. There is, of course, the possibility of some electromagnetic radiation from the movement of charged layers in the cloud and from the several electrical processes occurring in the interval between two successive flashes. But, the magnitude of the radiation is likely to be small and could be ignored for atmospheric noise purposes in the present state of knowledge and the needs of communication. The lightning activity of thunder-clouds extends over periods ranging from about half an hour to several hours. Idealizing the area of local activity to a circle of radius, 100 kms., it is possible to state that more than one thundercloud can become active within this region in the course of a Calendar day.

A lightning flash is the basic unit in the macrostructure studies of lightning and of atmospheric noise. In the case of some discharges, the acoustical wave may be heard as thunder. This is believed to arise from the sudden heating of the electrical discharge channel and consequent explosive expansion of the air in the vicinity of the discharge. The generation of this acoustical shock wave is a secondary process. There is, however, no evidence to support the view that all electrical discharges are accompanied by thunder but experimental work indicates that the severity of a lightning discharge follows the degree of violence of thunder.

The following types of flashes have been observed:

(*a*) Intra-cloud flashes in which the electrical activity is confined to the cloud mass and the discharges take place within the cloud;

(*b*) Air flashes in which the electrical activity extends to the surrounding air which may be ionized or neutral.

(*c*) Inter-cloud flashes in which the electrical activity may extend from one cloud to another. Almost horizontal streaks of lightning at cloud level may be seen during such discharges.

(*d*) Ground flashes in which the electrical activity extends from the cloud to ground.

(*e*) Ball lightning—This is strictly not a flash. This is stated to be in the form of a luminous globe reported to appear at or near the ground level during severe thunderstorms. It appears to be essentially a secondary phenomenon in the presence of high potential gradients. It is not of much significance for noise studies and does not appear to any significant extent in the tropics.

In any one lightning discharge, all flashes are never of any one type and the relative percentages of (*a*), (*b*), (*c*) and (*d*) can vary but there can be several occasions in the tropics when most of the flashes are of the types (*a*) and (*b*). The discharge processes occurring in intra-cloud flashes appear to exist in almost an identical manner in (*b*), and (*d*) also. Inter-cloud flashes do not constitute a high percentage of all types of flashes and, excluding them, in the other three types of flashes, the equivalent radiator could be considered as practically vertical or as an extremely short dipole depending on the frequency range in which the noise radiation is considered.

The lightning discharge has been extensively investigated. The methods of study are based on either (*a*) the electromagnetic field produced by it or (*b*) the property of reflecting electromagnetic waves by the ionized discharge channel. The latter is utilized in radar studies of lightning discharge. The wavelength chosen is such that reflections from water drops and ice crystals are weak but strong reflections are obtained from free electrons and ionized particles in the discharge channel. Pulse recurrence frequency determines the time resolution of this technique. Valuable information has been obtained by both the techniques mentioned.

A ground flash could be described as follows. When the air just below the cloud breaks down, a streamer called the leader moves towards the earth in the form of a series of quick steps. This is called the stepped leader. The length of a step is, ordinarily, between 40 and 100 metres and its duration is in the microsecond range. The time interval between the steps lies in the range, 40–100 microseconds. When the ionization of the air from cloud to ground is thus completed, a return current flows from the earth to the cloud, called the return stroke. The peak current in this return stroke is estimated to lie in the range, 10–100 kA. The duration of the return stroke is between 20 and 100 microscenods. If the charge neutralization by this return stroke is incomplete, another leader and another return stroke may follow. The subsequent leader is not ordinarily stepped in the region below the cloud base. This leader is called the dart leader. The median value of the number of return strokes is 4. Both the stepped leader and the return stroke can have branches, which end up in the air. When the branching of the return streamer occurs after it has entered the cloud, the branches are called M-components, During the time interval between successive return strokes, junction processes are reported to take place. These are the discharges occurring within the cloud, that allow tapping of charge centres at higher and higher levels of the cloud. Superimposed on these junction streamers, discharges called K-discharges occur.

The exact breakdown and discharge mechanism of cloud flashes are yet to be known. Brook and Kitagawa divide the mechanism into three parts, *viz.*, initial, very active and final portions. Of these, the final portion is similar to the junction process in a ground flash. (No categorical statement could be made to the effect that in a ground flash there is no initial and final portion.) The K-discharge recurrence period lies between 2–20 msecs and the duration of K-discharge is estimated to lie between 1 and 3 msecs.

Air flashes are believed to be similar to cloud flashes except for the difference that the disscharges end up in the air instead of inside the cloud. Not much is known of the inter-cloud flashes.

Cloud flashes constitute the major portion of all types of flashes. In the tropics where thunderstorm activity is the highest, they constitute 90 percent of all discharges. The number of inter-cloud flashes is small. Even in ground flashes, most of the phenomena believed to occur in a cloud flash do exist. Over a very wide frequency range, the source of atmospheric noise is the discharges inside the cloud. Hence, critical and detailed studies of the macro and micro structure of a cloud flash are most important from the noise point of view. Probably, the most convenient way of studying the macro and micro structure of a flash is an indirect one which utilizes band-limited atmospherics. Obviously, such studies have to be carried out over a wide range of frequencies. Even such methods pose important instrumentation problems.

The courser type of information needed for noise purposes is on the duration of lightning activity or lifetime of a thundercloud, the number of such thunderclouds that become active in a thunderstorm on a Calendar day including the probable hours of activity, the rate of flashing in a thundercloud, the duration of a lightning flash and the relative percentages of different types of flashes. In addition, information is needed on the sources of noise at different frequencies in a lightning flash. Different processes in a flash are responsible for noise of significant magnitude in different frequency ranges. Collection of data on these several items is basic for atmospheric noise purposes.

3.5. *Collection of Data*

As indicated in the previous sections, the information needed on thunderstorm days, thunderclouds, thunderstorms and lightning for atmospheric noise purposes is much more elaborate than what can readily be obtained from weather office and lightning discharge data. Some attempt was made in Bangalore to examine this problem and carry out both direct and indirect measurements., The gist of this work is presented in what follows:

Since the cloud base is about 3 kms. above the mean sea level in the tropics, reception of radiation from discharges within the cloud by line of sight propagation should be possible upto about 300 kms. Of course, it must be admitted that such radiation at SHF may be received for smaller distances due to bending of the ray in the atmosphere and attennuation due to rain, etc. At VHF and UHF, the direct ray range could be larger but may be much below 300 kms. Indirect experiments have shown that direct ray reception at VHF extends beyond 50 kms. At lower frequencies, 300 kms is a safe assumption for direct ray reception. Taking these facts into account, the following definitions need consideration:

(*a*) A day of local activity (DLA) is a day on which at least one storm is active within 300 kms from the point of observation.

(*b*) A day of local storm (DLS), is a day on which the centre of a storm is within 100 kms from the point of observation.

(*c*) A day of near storm (DNS) is a day on which the centre of a storm is within 50 kms. from the point of observation.

(*d*) A day of overhead storm (DOS), is a day on which the centre of a storm thundercloud is within 5 kms from the point of observation.

Our checks indicate the following relationship:

DLA = 3 (Number of thunderstorm days as recorded)

DLS = (0·5) · DLA

DNS = (0·25) · DLA

DOS = (0·02 to 0·05). DLA.

The above could be useful for deducing the required information from thunderstorm days weather office data.

The percentage of local storms days in the recorded thunderstorm days for Bangalore is respectively 20, 10 and 50 for March-May, June-August, and September-November. Ordinarily, local storm activity is confined to the hours between local noon and local sunset. In the case of frontal storms, activity may commence around local noon and continue till about an hour before the following sunrise. This has been traced to several thunderclouds becoming active at different places and times in the large area involved. There appears to be some interconnection between those thunderclouds like the one that exists between the different cells in an active thundercloud.

The duration of a lightning flash is an important parameter for noise purposes. Various values have been quoted. The value obtained depends on how one defines the duration of a flash. Often, one restricts oneself to the study of the very active portion of a flash, leaving out the initial and final portions. Sometimes, one calculates the time interval between the first pulse in a flash and the last one. Values would differ depending on which set of pulses one takes. Further, at UHF and SHF, and, probably at VHF, there is what may be called continuous noise radiation from a lightning flash. Further, the flash duration varies with the stage of activity of a thundercloud and with the possibility of ionospheric reflection of the pulses. All these problems have received considerable attention at Bangalore and the pointer is towards assuming a median value of 500 msec. The value is about 200 msec during the peak activity of a thundercloud.

The following data about the activity of a tropical thundercloud could be useful :

Lifetime of a thundercloud	..	3 hrs.
Peak rate of flashing	..	8 per min.
Duration of peak activity (time during which rate of flashing is above half of peak rate)	..	10 mins.
Total number of flashes per active thundercloud	..	700
Number of cells per thundercloud	..	5
Lifetime of a cell	..	35 mins.

The above are median values. If one needs flash density per sq. km. per day of activity, one could assume a value of one but this is not of great significance as what is wanted is flash density during the actual activity hours.

As regards the macro and micro structure of a noise burst arising from a lightning flash, a considerable amount of information is required. Some have been collected at Bangalore. It appears that the noise is continuous for the duration of a burst at VHF and higher frequencies and treating it as such, the expected peak amplitude can be deduced and this agrees with the experimental work. At HF and MF, there is probably a low value continuous background. Superposed on this are distinct pulses of about a millisecond duration. For 100 msec. of the burst duration, the median values of the number of pulses below 6 dB of peak, below 12 dB of peak and below 18 dB of peak are respectively 9, 13, and 20. The pulses are randomly distributed and follow the log-normal law. There is no information on the micro-structure of these pulses. The possibility of these having pulsive components which are randomly distributed cannot be ruled out.

On warm quiet days in the interval between two successive bunches of thunderstorm days in spring at Bangalore, lightning can be seen sometimes in cloud patches in an otherwise clear sky during the period, 15 to 22 hrs, for periods extending to several hours. This phenomenon is occasional and the noise radiation is small. Hence, it could probably be ignored for noise purposes.

3 6. *Source Characteristics*

From the discussion in the previous sections, it is clear that much more information on the source of atmospheric noise than is currently available will be needed. The crucial question is how much is to-be obtained by weather offices and how much by radio science organizations through a co-operative international effort. Probably, weather offices can furnish thunderstorm days data in terms of days of local storms and frontal storms. They can also log the commencement and end of thunder heard in terms of hours of day. They can log the days of overhead thundercloud activity.

The duration of a lightning flash, the duration of lightning activity, the rate of flashing per minute, the characteristics of local and frontal storms, the micro and macro structure of a flash, etc., are items on which proper information has to be obtained. It is not improbable that, in some cases, the characteristics may vary with latitude or from region to region.

The details of the information wanted depend on how accurately atmospheric noise is to be predicted, particularly for digital communication at VHF and above. It is useful to mention that such studies can be of value for the physics of lightning, for power transmission engineers and for other purposes. But the planning of world wide studies of this type belongs to international organizations.

4. ATMSOSPHERIC NOISE (1–9)

The sources of atmospheric noise may be within about 300 kms from the point of observation. Then, they are local sources. There may be sources lying between 300 and 1000 kms. They are near sources. Sources lying beyond 1000 kms are distant sources. For VHF and higher frequencies, the principal sources are those which are local and which lie within the cone of reception of the receiving antenna. Local, near and distant sources and this type distinction become important for MF and HF, and to some extent, for LF. At MF and HF, the noise from local sources is received by the space wave while the noise from near sources is received *via* the ionosphere. Distant source noise at MF and HF can be received only *via* the ionosphere but it will be so terribly attennuated that it gets reduced to about the background noise arising from other causes. At LF and VLF, near and distant source noise can be received by propagation along the ground. At VHF, reflection from the sporadic E and scattering can give rise to a low level background traceable to atmospheric noise

Characteristics of the ionosphere show diurnal, seasonal and other variations like those with sunspot number. Attenuation of the ground ray depends on whether the propagation is over the sea or land and the characteristics of the ground. These propagation problems add a new dimension to considerations of atomspheric noise and are very important. Propagation can restrict the received atmospheric noise to that from local sources, to that arising from near sources, or to that arising from both. And so on.

The major portion of atmospheric noise of significance at LF and above is traceable to local and near sources. Distant sources become important at frequencies below LF. This implies that atmospheric noise is most important only for the tropical sea and landmasses. Where man-made noise is very significant and is not controlled, atmospheric noise can mostly be ignored. Many of the developing and under developed countries lie in the tropical belt. In these countries, industrial development is not such that man-made noise is a problem for the largely scattered villages. Since these countries are not rich enough to employ sophisticated communication links and their requirements of channels are not large, they have to employ medium frequencies for broadcasting and HF for communication. In inaccessible hill regions, HF is the only choice. The majority of humanity belong to these developing and underdeveloped countries. Therefore, atmospheric noise interference will continue to be important for such countries.

The problems highlighted here are fundamental to the discussion that follows.

4.1. *The Noise Burst*

When the radiations from a lightning flash are picked up by a receiver tuned to a certain frequency and having a specified bandwidth, the output is a noise burst. The duration of a noise burst is the same as that of a lightning flash but the characteristics of the noise burst depend on the frequency and bandwidth of the receiver. The amplitude parameter of a local source noise burst is usually twice that of a near source noise burst. The distant source noise burst would be of very much smaller magnitude at frequencies above LF. When communication is to be established, we think in terms of at least 90 per cent of the time satisfactory service during a short period of time like a minute. Therefore, from the practical point of view, the noise occupying 10 per cent of the time is all that needs to be studied and evaluated. About 12 noise bursts occupy 6 seconds, *i.e.*, 10 per cent of the time. Hence, if about 12 noise bursts from local sources are present, the other noise bursts can be ignored in practical noise evaluations. If this approach is adopted, studies and evaluations become simpler and more rational. The other alternative is to think in terms of all noise bursts from all sources contributing to something similar to a continuous form of noise. In such a case, the noise will have a complicated form and actual measurements may clip high amplitude noise because of the limited dynamic range of the measuring equipment. Further, studies would no longer be in terms of noise bursts, the natural units in terms of which the noise has to be studied and evaluated. An extremely large number of noise bursts of amplitudes lying within a range of 20 dB which could justify a continuous form of noise is an extremely rare phenomenon in the tropics at frequencies above the VLF. This cannot probably be ruled out as a possibility of more frequent occurrence in temperate latitudes. Against this background, serious thought may have to be given to presenting atmospheric noise data in alternative forms. Since the structure of the noise burst can vary with frequency and bandwidth, thought may have to be bestowned on presenting noise data for different frequency ranges separately. Since there is systematic hour to hour variation in lightning activity, the desirability of giving hourly values in place of time block values may have to receive consideration.

4.2. *Structure of a Noise Burst*

The structure of a noise burst depends to a considerable extent on the frequency at which it is studied and the bandwidth employed. Studies at VHF indicate that the noise in the noise burst can be regarded as white noise. Probably, this conclusion is valid at SHF also. But there is no experimental evidence to firmly support this view. As we move down to frequencies below 30 MHz, the indications are that there are innumerable number of distinct pulses of approximately millisecond duration, but of varied amplitudes. In addition, there may be a general background, but it is difficult to categorically make any assertion on the same. The distinct pulses could be grouped as those within 6 dB of the peak amplitude pulse in the noise burst. These pulses and the time interval between them indicate that they probably arise from what lightning discharge investigators call K-type discharges. In addition, there are pulses which are 12 dB below the peak amplitude pulse mentioned earlier. There are also pulses which are 18 dB below the peak amplitude pulse. It is not known whether these different pulses are to be traced to different phenomena in the lightning discharge. There could be pulses which are of amplitudes very much lower than 18 dB below the peak amplitude pulse. Detailed investigations on these become difficult and no categorical statement can be made. At MF and the lower region of the HF, the predominant pulses are mainly those which are within 6 dB of the peak amplitude pulse. No investigations have been carried in Bangalore on the structure of a noise burst below MF and hence no statements can be made. However, it is very likely that at LF, the pattern described for MF may correspond to realities.

It will be seen from the description given above that a generalised statement about the structure of a noise burst to cover the entire frequency range of interest to communications is difficult. However, the structure of a noise burst and the pulslve character become important when one thinks of data transmission and interference by a noise burst. When one thinks in terms of voice communication, one could consider the noise burst in its entirely and deal with the same in terms of its quasi-peak amplitude.

4·3. *Random Events*

All natural phenomena are basically random processes. But a particular parameter that we study may be the result of a large number of random processes which may be independent of each other. And so on. The problem that the noise investigator is interested in is to find out the type of statistical law already known which a certain noise parameter follows within the order of accuracy required for purposes of furnishing noise data. This is a very important consideration to be kept in view for purposes of simplicity of presentation within the required limits of accuracy. A large number of studies carried out at Bangalore indicate that many parameters pertaining to atmospheric noise follow the log normal law. Thus, the duration of a noise burst, the time interval between noise bursts, the time interval between pulses within a noise burst, the amplitude of a noise burst over a short period of time, the median value of the amplitude of a noise burst as examined over a long period, etc., all follow the log normal law. This is an interesting result of practical significance.

4·4. *Types of Atmospheric Noise*

The term, " short period, is being construed in what follows as corresponding to a few minutes. It may be anywhere in the range of 1 to 10 minutes. Perhaps, future requirements may dictate studies for much shorter periods for evaluating short term characteristics. In this connection, it may be stated that when the period considered corresponds to less than one second, it is best to give details of the structure of a noise burst as the short term characteristic. For much higher periods, the problem does not arise as the natural unit is the lightning flash and it lasts about 500 milliseconds.

When the structure of atmospheric noise over a short period of time like a few minutes is examined, it is found that the noise is not always and at all frequencies of the same type. Sometimes, the noise is of the continuous form with no distinct sets of peaks existing in the form of bursts above a continuous background. This type of noise is called type 'A' noise. This type of noise may be of the same order of magnitude as other forms of interference. In such a case, it can be ignored. But, there are cases where this form of noise of significant magnitude also exists. It is best that this form of noise is treated approximately as equivalent to white noise. This form of noise has been observed quite frequently at the lower end of LF and below LF in the tropical regions. It is occasionally observed for some periods of time in the MF and HF bands. When it is so observed, the presence of some peaks in the form of bursts is always discernible. This form of noise arises when a very large number of noise bursts of the same order of magnitude are received at a point of observation. It is possible that this is the form of noise which is frequently observed at higher latitudes over a wide range of frequencies.

Quite frequently, in the tropical latitudes, distinct noise bursts well separated from each other are observed. Their number per minute may vary over the range 5 to 40. Ordinarily, the most probable values of the number per minute are between 10 and 20. Even in such cases, there should be a background of type 'A' noise but its amplitude is negligible compared to the burst form of noise. Further, as aleady discussed, communication engineers think in terms of getting 90 percent of the time satisfactory service in a short period of time. Therefore, the highest magnitude noise occupying 10 per cent of the time is what matters and what should be studied. If this view is taken, most of the time, at MF and HF, atmospheric noise is of the burst form. It is this burst form at VHF and higher frequencies that can be observed only when there is lightning activity within distances of the order of 50 kms.

This burst form of the noise can be further classified into two types. The first type consists of distinct and well separated bursts which do not exceed about 20 per cent minute normally and which are of large magnitude. This type of noise arises from local lightning activity as described earlier and is called type 'C' noise. When noise bursts are received *via* the ionosphere the bursts are not sharp and the number is ordinarily more than 20. This form of noise has been called type 'B' noise. However, for dealing with the noise problem, the distinction between type 'B' and type 'C' is not very important.

It is quite possible that at higher latitudes, the atmosphere noise observed roughly correspond to type 'A' noise as described earlier over a wide range of frequencies. Therefore, the crucial point to consider is whether we furnish data in one uniform way for all regions of the world or make a distinction between tropical regions and temperate regions. Similarly, another important point to consider is the range of frequencies for which noise data has to be furnished.

4·5. *Atmospheric Noise Data*

Before furnishing atmospheric noise data, the following problems have to be critically examined and decisions taken:—

(*a*) Where and for what purposes is atmospheric noise important?

(*b*) Can local storm noise be ignored everywhere as something rare?

(*c*) Is it satisfactory to furnish noise data for all regions of the world for all purposes and at all frequencies in one standardised form or should attempts be made to furnish data in different ways for different regions, for different ranges of frequencies and for different purposes?

The discussion in the previous section has already highlighted some thinking in respect of the questions formulated above. Atmospheric noise is basically of great importance even today at tropical latitudes. Therefore attention will have to be paid to furnish atmospheric noise data as tropical latitudes in a way different from the way in which it is furnished for higher latitudes. This is a problem to which attention will have to be paid. Specific mention may be made of the fact that over a short period of time, the noise is of the burst form over a wide range of frequencies. The magnitude of the noise is much larger than what is normally expected at higher latitudes. Other forms of noise like man-made noise are negligible in the scattered villages of tropical areas. Further, if data are furnished for the burst form of boise, it is possible to give median values and standard deviations for noise levels on days of local actvity and on other days. Further, the noise shows distinct hour to hour variation called systematical variation over certain periods of day in the tropics. Such variations may be observed at higher latitudes also, but they may not be for such a large range of hours or so distinct as in the tropics.

The other problem which will become increasingly important is to furnish the magnitude of atmospheric noise arising from local and near thunderstorms at VHF and SHF. This noise is received at the receiving point either *via* the sporadic 'E' or by scatter. The magnitude of this noise could be important for radio astronomy also. In addition, when there is lightning activity within the cone of reception and within a distance of about 50 kilometres from the point of observation, atmospheric noise is of sufficient magnitude to interfere with television, data communication, etc. In such cases, it may be useful to furnish the noise data, number and period of local lightning activity and indicate the most probable hours and seasons when it can be expected. In addition, information on how frequently it can be expected is also important.

Atmospheric noise data has been furnished in a form to be described in the next section several years back. If the data is to become more reliable and more useful, the problem of revision of the data already furnished assumes considerable significance.

5. STUDIES OF ATMOSPHERIC NOISE [1–9, 23–49, 55, 57–59, 62–75, 83-90 93–99, 101–104, 107, 108, 111–118, 120, 122–124, 127, 129–133, 140–145, 149–151, 153–154, 158–175, 178, 181, 187, 189–191, 201–204, 208-212, 214–216, 224, 233–236, 241–256, 258, 260, 262–265, 270–273, 275, 282-286, 293–296, 303–304]

Atmospheric noise has been observed by several investigators the world over. It has also been studied in a quantitative way by several investigators. The references will furnish abundant information of this matter. Extensive and detailed investigations were carried out by the Radio Research Board, UK, the National Bureau of Standards, USA and in India. Valuable studies were also carried out in Australia and other countries. The International Consultative Committee on Radio Communication (ICCR) has been vitally concerned with the furnishing of noise data for the planning of communication systems and have furnished atmospheric noise data from time to time.

The object of this section is to give some detailed consideration to more extensive types of work While this is being done, it is to be stressed that it does not in any way mitigate the importance of valuable contributions made by individuals and organisations not specifically referred to.

5.1. *Historical*

Through listening, atmospheric noise was noticed and classified into different types like clicks, grinders and sizzles. A number of observers demonstrated that the source of all atmosphere noise is the natural lightning discharge associated with thunderstorms. Investigations by the British and Australian Radio Research Boards produced no evidence that was incompatible with the hypothesis that atmospherics which gave rise to atmospheric noise had their origin in lightning flashes.

Actual measurement of atmospheric noise has been made since 1922 at a number of locations and over periods ranging from a few days to several years. In the initial stages measurments were in the frequency range 15 to 60 KHz. Later, measurements were extended to other frequencies upto 30 MHz. Some measurements and studies have also been carried out at much higher frequencies. During 1923–26, certain general features of atmospheric noise were discerned as a result of measurements made in England, United States and Panama. During 1929–32 regular measurements were made in England and USA in the frequency range 2–20 MHz. Some measurements were also made at Paris and Berlin. During 1938–40 some meassurements were carried out in India. During 1943 routine observations of atmospheric noise were made by the BBC in the HF band. Measurements were also carried out in Japan. Considerable interest was evinced on the characteristic of atmospheric noise during world war II and the Interservices Bureau made several studies.

Quite often, measurements were of a subjective character. Sometimes, even when the measurements were objective, the problem of re-producibility of the results and comparison of the same as obtained by different investigators posed a serious problem. However, the early work really laid the foundations for more systematic work. Without this early work, any planning of systematic work would have become impossible.

5.2. *Problem of Noise Meters*

Since the early days of measurement, the crucial problem that faced investigators was the one of noise meters. Since the parameters of the noise necessary for assessing its interfering effect to different types of services were not known, attempts were principally concentrated on determining what can now be described as an amplitude parameter. The measurements attempted to evaluate r.m.s., average, or peak value or of the fractional time during which the distrubance exceeds some previously assigned value. The calibration of the instruments created its own problems with the result that one was required to think in terms of comparison of different types of noise meters.

One of the crucial problems in the measurement of atmospheric noise is to decide on the type of measurement to be carried out. In one type called the subject type, the measurement carried out was of the signal strength necessary to satisfactorily overcome the noise. In the second type, an objective noise meter was developed which gave information on the noise and its characteristics in terms of pre-set considerations. Thus, the time constant for one type of meter was determined in such a way that the meter indications corresponded as nearly as possible to the annoyance caused to the ear.

It must be mentioned that the real characteristics of the noise can get mutilated by the time constant employed in the noise meter. Hence it is extremely important to know the time constant properly. The magnitude of the noise does depend on band-width and the band-width has to be specifically stated. The characteristic of the aerial has an influence on the magnitude obtained for the noise and therefore requires specific mention. All these details have been examined in the last three decades and the results furnished in the later periods give specific information on the points mentioned. However, if one needs to know the number of pulses present in the noise whose duration is very short, *viz.*, a few micro-seconds or less, there appears to be no noise meter which can do the job directly.

5.3. *Radio Research Board, United Kingdom*

The RRB of UK have been the pioneers in the field of atmospheric noise investigations on a world-wide scale. It is as a result of their valuable investigations that one could appreciate the noise problem in a much better way, although the data they have furnished in their special reports may not be of direct significance for actual use today.

In their method, low speed morse signals are fed along with the received atmospheric noise to a receiver. The strength of the signal is raised gradually till the observer records them with 95 per cent of the time intelligibility. Measurements are taken every hour at a pre-determined number of spot frequencies with a suitably chosen band-width. The first world wide measurements were in the 2–20 MHz range using a band-width of 10 kHz by the method described. The data collected have been furnished. The actual measurement depends on the judgement of the observer and the results are basically of value for one specific service, *viz.*, low speed morse signals.

Similarly measurements have been carried out in the frequency range 15–500 kHz using a band-width of 300 Hz and a signal, which is electronically keyed at a rate of 2 per second. The results have been reported. Modified versions of this method have been used by certain organisations in India, France, Japan, Australia and USA.

5.4. *National Bureau of Standards, USA*

The National Bureau of Standards designed the ARN–2 noise recorder for measuring atmospheric radio noise in an objective way. They installed this equipment in a network of 16 noise recording stations distributed throughout the world.

In the design of the equipment, they think in terms of the resultant envelope of noise arising from type 'A', type 'B' and type 'C' forms atmospheric noise. Information obained by a study of this resultant envelope voltage is useful as an indication of a lumped or integrated effect. But, at any given time, the relative contributions from the three different forms of atmospheric noise may vary. Consequently, the results from the studies of noise envelope may not be of great utility value for understanding the characteristics of individual noise bursts. The results furnished one way of giving data on atmospheric radio noise. Since this method has been accepted on an international basis for furnishing noise data, data which is still valid today, a brief description of the method and the results are furnished in what follows.

The ARN–2 noise recorder utilses a 21·75 feet vertical aerial installed in the centre of an elevated ground system. It can record noise over 8 fixed frequencies in the range 13 kHz–20 MHz and at a bandwidth 200 Hz. The three parameters of noise measured with this noise recorder are (*a*) average noise power, (*b*) the average of the envelope voltage and (*c*) average logarithm of the envelope voltage. The linear output at the detector is averaged with a 100 seconds time constant and the logarithmic output is averaged with 25 seconds time constant. A 15-minute recording is made on each of the eight frequencies, two at a time during each half hour and these 15 minutes samples are taken as representing the noise conditions in the full hour.

The mean noise power averaged over a period of several minutes is expressed as effective noise figure, F_a. The other two parameters, namely, the average and average logarithm of the envelope voltage are expressed in decibels below r.m.s. voltage. It is also reported that, from these measure parameters, it is possible to derive the amplitude probability distribution of the instantaneous envelope voltage.

Based on the experimental observations at the different stations and associated data on distribution of thunderstorm days as well as conditions of propagation, the NBS published estimates of noise. The data were presented in the form of isolines of equal average noise power on a cylindrical projection map of the globe for the four seasons of the year. Approximate inverse frequency nature of variation of noise and a combination of two log normal distributions for the median values were also indicated. Variation of the median noise over four-hour time blocks during the four seasons of the year were also given for the frequency range 10 kHz–45 MHz.

This method of carrying out noise measurements and furnishing noise data is probably useful at high latitudes. In tropical latitudes where local storm noise preponderates the method has its limitations. Firstly the available dynamic range of the instrument is such that it may cut off high amplitude local storm noise. Consequently, studying all the three types of atmospheric noise together can mask the effects of local storm noise. Thirdly, the large time constant employed prevents short duration large variations from getting properly reflected in the data.

The investigations of the NBS were monumental and of great utility value. They form the basis on which the ICCR have furnished noise data on an internationally agreed basis. However, the question that arises is whether we would think of the median value of noise over a short period of time or the highest value of noise prevailing for 10 per cent of the time.

5.5. *Noise Data, ICCR*

The ICCR, in their report No. 322 which is a modified and important version of their earlier report No. 65, have provided noise data on a world wide basis. The data collected at most of the stations using the ARN-2 noise recorder and other data have been utilised in arriving at an estimate. 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 six 4-hour time periods *via.*, 00–04 hours LMT, 04–08 hours LMT and so on. The aggregate of the corresponding 4-hour time periods of the day throughout a season constitutes a time block. The basic parameter chosen for presenting the data is the effective noise figure, F_a. Estimated medain hourly values of F_a, denoted by F_{am} are given for each time block and the variations in this parameter show systematic diurnal and seasonal variations of the noise. Variations of the hourly values within a time block are treated statistically and their extent is indicated by the ratios of the upper and lower deciles to the time block median.

Noise grade maps are furnished giving the data of F_{am} at 1 MHz and for all time blocks and seasons of a year. Graphs are drawn for various noise grades enabling determination of F_{am} at any frequency.

The limitations of the NBS methods of measurement have already been pointed out. They are valid for the CCIR data also. In view of the reasons earlier furnished, the CCIR method of giving data is not likely to be as useful as it is deemed to be at tropical latitudes.

There is correlation between noise levels at different frequencies. But experimental studies indicate that this correlation decreases as the frequency separation increases. Hence, it is probably much more appropriate to furnish noise grades at two frequencies or eveh three frequencies rather than at just one MHz. Data are provided for a time block. Experimenttal studies show that there is systematic hour to hour variation of noise levels. Hence, it is probably more appropriate to give hourly data rather than time block data.

The estimate of the uncertainties in predicting correct values of F_{am} is given. This exceeds 6 dB in many cases. The year to year variation due to the natural phenomenon is not likely to exceed 2 or 3 dB. Hence, the significant portion of the uncertainty in predicting the correct value appears to be due to the presentation technique. This is a question which needs further examination, 5.6. *Burst Studies*

Extensive investigations have been carried out on noise bursts arising from lightning flashes in India. A special feature of these investigations has been the simultaneous study of lightning flashes and noise bursts. Both short term and long term amplitude and time parameters of noise bursts have been investigated in detail from 30 kHz to 60 MHz. The investigations have been systematic and have been carried out in several cases round the clock. Data have been obtained not only for a complete year but repeated data have been obtained to check on the accuracy of the data obtained during a previous year. Every attempt has been made to correlate the noise burst data with lightning flash data during local thunderstorms. Correlation between noise levels at different frequencies have also been investigated in detail. In addition, special studies have been made of the structure of noise bursts at various frequencies. The investigations are thus complete and self-consistent. As a result of these investigations, it has been found that it would be most appropriate to furnish noise data for the burst form of the noise at tropical latitudes. The basic parameters of noise burst examined are the duration of the noise burst and the quasi-peak value of the noise burst. This quasi-peak value corresponds to the annoyance that would be caused by the noise burst to the ear. As a result of extensive investigations, it has been possible to deduce conversion factors to convert this quasi-peak amplitude into a peak amplitude and an average amplitude and an RMS amplitude of noise burst. The data furnished as such is extremely simple to utilise and is in terms of a limited number of parameters. Although the data has been furnished for India only, it is extremely simple to furnish data of a similar character to any other tropical country by only drawing the local activity days maps. These maps can be drawn by multiplying the weather office records of thunderstorm days by a factor of 3. It is felt that this method of furnishing noise data is likely to prove more useful at tropical latitudes, where atmospheric noise is really important. Further, having regard to the underdeveloped nature of the countries in tropical latitudes and the frequencies they have to employ for communications, atmospheric noise data is of paramount importance to these countries. Hence precise data of this type may be much more useful.

The basic approach is as follows :—

Short term represents the basic time unit and is defined as a period of five minutes. It represents the shortest time in which all the characteristics of the noise can be properly studied. It is long enough to justify the application of statistics to the data, but short enough to avoid the effect of time variations even under conditions of a local storm. It is adequate to assess properly the degree of satisfaction in the reception of all types of signals.

In n short term units, if the reception is satisfactory for $0 \cdot 5\ n$ of the units, it is said that the reception is satisfactory for 50 per cent of the time. But, in a given unit in which the degree of satisfaction is considered adequate, the designers of radio communication system expect at least 90 per cent of the time satisfactory service. Hence, in the time stretch of 300 seconds, it is expected that the corruption of signals by the noise is unnoticeable for at least 270 seconds. Often, much better standards are required. Hence short-term noise studies are most properly restricted to examinng the characteristics of the noise of the highest amplitude prevailing for 30 seconds, *i.e.*, occupying only 10 per cent of the time. Such a procedure enables the selection of one of the 3 components, *viz.*, the one of the highest magnitude for study during five minutes and leads to the collection of information in detail. A short term median value of a noise amplitude, therefore signifies the noise level for 95 percent of the time satisfactory service. Similarly, the higher decline value signifies noise level for 99 percent of the time satisfactory service.

Over a short period of time, the amplitude of noise burst follows a log normal distribution. There is thus a median value and a standard deviation When the median values thus obtained for a short period of time during an hour are plotted for all the days of the season, we get long term characteristics. This also has a long normal distribution. Incidentally, the days of a season have to be separated out as days of local activity and as days which are not of local activity. Days of local activity correspond to high noise level days and other days to low noise level days. The days of local activity can be identified by checking on the noise level between 16 and 18 hours at a high frequency like 3 MHz.

It has been observed that, in the tropics, at least for the MF and HF, the noise data to be furnished is only for the burst form of the noise. A continuous form of type 'A' form of the noise can be ignored. The noise data can be furnished at 1 MHz and 1 kHz band width. It can be converted into any other band width by applying the square root band width law. This is approximately correct. The data can be converted to corresponding data at any other frequency by applying the inverse frequency relationship. The quasi peak amplitudes are furnished in the data and can be converted into average r.m.s. or peak amplitude parameters by appropriate conversion factors. The manner in which the data are furnished would be clear from data sheets No. 1 and 2 and No. 3 reproduced in the Appendix.

At VHF, atmospheric noise data are furnished at 100 MHz for a pass band of 1 kHz. Values for other frequencies and band widths can be deduced by applying the inverse frequency and the square root band width laws. The r.m.s. value of the equivalent fluctuation noise at 100 MHz and 1 kHz pass band, present for 10 per cent of the time, for about an hour at a time atleast once od a thunderstorm day between local hoo and midnight is 20 ± 10 dB above 1 μV/m. VHF noise radiation travelling *via* the sporadic E-layer or by troposcatter can contribute continuous noise of the order of $0 \cdot 1$ μV/m at 100 MHz and 1 kHz pass band. This noise will be present even in remote places during thunderstorm seasons.

Studies of the duration of noise burst have shown that the median value of a duration of noise burst is about 500 milliseconds. The distribution is log normal.

The number of noise bursts received per minute has also been studied. Its distribution is log normal and the median value is 20.

The structure of a noise burst has also been studied and the results have already been given earlier. The relevant data about the one millisecond pulses of different amplitudes are furnished in the Appendix.

6. INSTRUMENTATION [23, 39, 63, 84, 101]

Any improvement in the furnishing of noise data or in the extension of the data to a wider range of frequencies would need proper and systematic measurements. In such measurements the most crucial question that poses problems is one of instrumentation. Firstly, if atmospheric noise characteristics have to be evaluated at very high frequencies like UHF and SHF, what is the type of data that should be furnished and for what purpose and what is the type of measurement that has to be carried out become important questions. Secondly, if the fine structure of noise is to be presented, the manner in which data has to be collected for these purposes poses its own problems. Thirdly, if the data has to be furnished in a more precise way even where it is available, the question of the time constant of the meters employed as well as the dynamic range of the meters become important.

So far as noise burst structure is concerned, it is best to carry out simultaneous studies of lightning by observation and the recording of the structure of a noise burst. When such a structure has to be recorded, even the C.R.O. has its limitations. Under the circumstances, from the scientific point of view, the problem that poses itself is one of instrumentation. It is being mentioned here only incidentally for the simple reason that this question is much too large to be covered adequately through a section of a paper largely devoted to a wide variety of other problems.

7. Conclusion

The paper gives a critical review of the noise problem and highlights the studies carried out and their limitations. Wherever possible, an attempt has been made to project into the future requirements. Examined from this angle, it has been pointed that weather offices may be called upon to give the data on thunderstorm days in an improved form. It has also been pointed out that simultaneous studies of lightning flashes together with a study of the structure of noise bursts at different frequencies is an urgent necessity.

Before proceeding to think in terms of the future, it would be useful to define in precise terms the purposes and the regions in which an atmospheric noise is really important. This question has also been dealt with to the extent possible in the paper.

The general review appears to indicate the following for serious consideration:—

(*a*) It is desirable to give data on an hourly basis rather than on a time block basis to avoid systematic variations from getting masked.

(*b*) Since noise level correlation with frequency decreases as the frequency separation increases, it is desirable to furnish noise data at a number of spot frequencies, *viz.*, an LF, an MF, an HF, a VHF, an UHF and an SHF.

(*c*) Data could be furnished for three different values of sun spot numbers.

As has been discussed within the body of the paper, over a very wide range of frequencies, atmsopheric noise is basically a tropical problems It is in the tropics that precise data on atmospheric noise is most urgently necessary. Examined from this point of view, it appears to be most desirable to furnish data separately for the tropical regions and for other regions. If need be, one could think in terms of at least funishing an alter native set of data for the tropical regions. In the tropical regions, whe one thinks in terms of more than 90 per cent of the time satisfactory servic in a short period of time, the ideal form in which data should be funishe is in terms of the burst form of noise. Presentation of data in terms of nois burst has an added advantage that it is in terms of the natural unit.

Looking ahead, optimal design of a complete radio communicatio system will require the interference environment of radio noise from lightnin over the entire electromagnetic spectrum. This can only be furnished in terms of appropriate parameters of a macro-structure, a micro-structure and a hyperfine structure of the noise. The macrostructure can only be in terms of noise bursts in their entirety as a noise burst corresponds to a complete lightning flash. The microstructure corresponds to the structure of a noise burst in terms of integrated impulses and background and the hyperfine structure corresponds to the composition of the impulses in terms of primary pulses. Investigations of relevance to this approach have been sufficiently stressed and adequately described.

8. REFERENCES

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APPENDIX I

Data for Tropical Rogions

DATA SHEET NO. 1

Atmospheric radio noise data for noice communication

f = Frequency (MHz) in the band, 0·3–30 MHz.

B = Bandwidth (kHz) at 6 dB down.

N = *Noise level at 1 MHz for a 1 kHz bandwidth*

$N(B)$ = Noise level at 1 MHz in a bandwidth, $B = N \cdot \sqrt{B}$ (1)

$N_f(B)$ = Noise level at f in a bandwidth, $B = N(B)/f$ (2)

H = N for days of local activity

L = N for days other than the days of local activity

Z = Background of minimum interference for the band, 0·3–30 MHz for a 1 kHz bandwidth (average value) = 0·2–0·5 μV/m

$Z(B)$ = $Z \cdot \sqrt{B}$

Effective noise level $= \sqrt{[N_f(B)]^2 + [Z(B)]^2}$ (3)

$Z(B)$ can be neglected in most cases

Short and long term distribution of N–log–normal.

Standard deviation for $H = 8$ dB.

Standard deviation for $L = 4$ dB.

Short term standard deviation for $N = 4$ dB.

TABLE I

Seasonal median values of N ($\mu V/M$)

Time (LMT)	0000–0400		0400–0800		0800–1200		1200–1600		1600–2000		2000–2400	
Season	H	L	H	L	H	L	H	L	H	L	H	L
Spring	30	15	15	10	0	0	15	0	15	10	30	15
Summer	30	15	15	10	0	0	10	0	15	10	30	15
Autumn	15	10	15	10	0	0	10	0	15	5	15	10
Winter	15	10	10	5	0	0	10	0	15	5	15	10

DATA SHEET NO. 2

Atmospheric radio noise data for data communication

Q = N_f (B) from Data Sheet No. 1

$Z(B)$ = Background of minimum interference from Data Sheet No. 1

A = Average value of the equivalent continuous noise due to Q

R = rms value of the equivalent continuous noise due to Q

P = value of the highest peak amplitude.

Time functions of P—*see* Table III.

For deducing the actual values of P, A and R, from the values of Q, use the statistically assessed conversion factors given in Table II.

TABLE II

Conversion factors for P, A, and R (dB)

Frequency range (MHz)	P/Q	A/Q	R/Q
0·3–3·0	5·5	—9	—6
3·0–10	5·0	—8	—5
10 –30	4·5	—6	—4·5

Effective peak amplitude $= \sqrt{P^2 + [Z(B)]^2}$

Effective average value $= \sqrt{A^2 + [Z(B)]^2}$

Effective rms value $= \sqrt{R^2 + [0\cdot 8\, Z(B)]^2}$

In most cases, $Z(B)$ can be neglected.

DATA SHEET NO. 3

Desirable signal-to-noise ratio (dB)

Data for some common types of services

Service	Signal/effective noise level
Double side band telephony 100% modulated	20
Secondary broadcasting	40
Primary broadcasting	60
Manual CW telegraphy	−6
High speed CW telegraphy	6

Note: Effective noise level is the value obtained from equation (3) in Data Sheet No. 1.

TABLE III

Time interval between peaks in a burst

(P = amplitude of highest peak)

Amplitude range	Approximate number	Distribution	Median value (ms)	Standard deviation in log-units
P to $P/2$	10	Log-normal	33	0·32
$P/2$ to $P/4$	20	Log-normal	20	0·22
P to $P/4$	30	Log-normal	12	0·22