STUDIES IN IONOSPHERIC PHYSICS USING EXTRA-TERRESTRIAL RADIO NOISE

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PREFACE

Since the discovery of the layers reflecting electromagnetic waves in the earth's high atmosphere, their physical characteristics such as virtual heights and critical frequencies have been extensively investigated. Ionospheric absorption and scattering of radio waves have received much less attention, particularly in low latitudes. Radio noise from the galaxy serves as a convenient source outside the earth's atmosphere for studying the changes in the ionosphere.

The thesis embodies the results of the author's work on the design and construction of a 25 Mc/s cosmic radio noise recording equipment at the Physical Research Laboratory, Ahmedabad, its maintenance for a period of two years, the tabulation and analysis of the data and discussion of the data collected during the period March 1957 to December 1959.

It has been found convenient to divide the total attenuation into two components: (i) A daytime symmetrical component around the local noon and (ii) A non-symmetrical component which does not obey $(\cos \chi)^n$ law.

The seasonal and diurnal variations in each case have been discussed, and comparison is made with similar observations made at other places. The absorptions at Ahmedabad are much larger than in middle latitudes and the dependence on electron densities in the F_2-region definite and large. Electron-ion collisions in the F_2-region appear to have larger effect on the absorption than the collisions of electrons with neutral atoms and molecules in the D and E regions.

The sudden cosmic noise absorptions (SCNA's) associated with solar flares from February 1959 to August 1960 have been tabulated and briefly discussed.

During magnetic storms, the F_2-layer gets very much disturbed and the amount of F-scatter substantially reduced. "Cosmic-noise" measurements provide a valuable means of studying ionospheric disturbances associated with geomagnetic storms. The study has provided new information about the variations of cosmic radio noise at a station, situated near the peak of F_2 critical frequency, and the relationship of the cosmic radio noise absorption with electron densities in the F_2-region including the effect of magnetic storms.

The author was mainly responsible for the constructing and maintaining the cosmic-noise equipment and the scaling, computation and analysis of the cosmic-noise data throughout the period under investigation.

Countersigned

K R Ramanathan

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References and acknowledgements to other workers and authors have been made in appropriate places. It is hoped that there are no serious omissions.

(R.V.Bhonsle)

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CHAPTER I

INTRODUCTION

1 - COSMIC RADIO NOISE

Cosmic radio noise was discovered in 1932 by Karl G.Jansky[1] of the Bell Telephone Laboratories in the course of observations of the direction of arrival of atmospherics. His observations on 20 Mc/s showed that in addition to atmospherics, there was a steady source of radio waves in the direction of the Milky Way with a pronounced maximum near the centre of the galaxy. Jansky's work was followed up by Grote Reber[2,3,4] who carried out galactic surveys on 160 and 480 Mc/s. In 1946-47, Hey, Parsons and Phillips[5] and Bolton and Stanley[6] discovered the existence of discrete sources of radio noise. Cosmic radio waves are composed of different distinct types of radiation : a hydrogen line emission restricted to a narrow frequency range (Ewen and Purcell[7]) near 1420 Mc/s, and emission of a broad spectrum extending over practically the whole of the radio frequency range and arising both from temperature radiation and from synchrotron radiation. The continuous radiation from the milky way is similar to random noise and is unpolarised. The radiation from discrete sources show marked fluctuations both in intensity and direction. These fluctuations are analogous to the twinkling of stars and have been shown to be caused by irregularities in the ionosphere. Radio observations are now extensively employed to study both galaxies and discrete sources. Radio waves have an advantage over light in such studies, because they are not absorbed by dust-clouds of interstellar space.

2 - APPLICATION OF COSMIC RADIO NOISE FOR IONOSPHERIC STUDIES

Since cosmic radio waves have to pass through the atmosphere before they reach the earth, they are subject to deviation and absorption in the atmosphere. The atmosphere may be considered to be partially transparent from about 20 Mc/s to 3000 Mc/s. At the lower frequencies the ionosphere can modify the intensity by absorption, scattering, and emission and by producing divergence or convergence of beams. From the point of view of astronomical studies, these effects are an inconvenience as they complicate the interpretation of observations. But from the standpoint of geophysics they provide a means for studying the terrestrial ionosphere. The method supplements the usual technique of studying the ionosphere by echo sounding, in that the waves pass through the whole of the ionosphere, including the part above the level of maximum ionization of the F_2 layer.

3 - SUMMARY OF THE IONOSPHERIC STUDIES USING COSMIC-NOISE METHOD

In one of the earliest observations of cosmic radio noise on 20 Mc/s Jansky[1] noticed that during the day, the intensity of cosmic radio noise was lower than that during night and he attributed this to ionospheric absorption. In 1940, a series of observations were made at 18.3 Mc/s by (Shain[2]) in Australia. He measured the intensity of cosmic radio waves from the zenith over a substantial fraction of the year. During this interval, different parts of the sidereal sky passed overhead at different times of the day, and so under different ionospheric conditions. Shain observed that the intensity for any part of the sky was high when the critical frequency of the F_2 region at the time in question was less than 9 Mc/s. If it exceeded this figure, the observed intensity showed a progressive decrease. Although the ionospheric attenuation was small under certain conditions, it could be measured without difficulty. Mitra and Shain[3] made a detailed study of ionospheric absorption on 18.3 Mc/s at Hornsby (lat.34°S, long.151°E). They showed that the total attenuation could be divided into two components one, a symmetrical day-time effect with maximum at about noon, which they attributed to absorption in the D-region, and the other an absorption in the F_2-region. The observations of the so-called D-region absorption showed diurnal and seasonal variations similar to those observed by other methods. The F_2-absorption depended on the critical frequency of F_2 but not on the height of base of the F_2 layer. They noticed an excess of night-time F_2-attenuation over daytime attenuation for the same value of the critical frequency of the F_2-region and attributed it to the scattering of radio waves by the irregularities in the electron distribution in the F_2-region. On comparing the curves of F_2-absorption, they found that the measured absorption increased more rapidly with f_oF_2 than what was expected on theoretical grounds.

Blum and others[10], working on 29.5 Mc/s, at Marcoussis (lat. 48°38'N, long. 2°13'E) found that the absorption varied linearly with f_oF_2, while according to Mitra and Shain a curvilinear relation hold good. At these temperate latitudes the total absorption of extra-terrestrial signals received from the zenith at frequency 13.8 Mc/s was of the order of 0.5 to 2 db, of which approximately 1 db took place in the D-region at noon. There was a dependence on solar zenith angle with exponent 'n' equal to 1.1 in summer, 0.9 in equinoxes and 0.5 in winter at 13.8 Mc/s. At 29.5 Mc/s at Marcoussis, the total zenith absorption rarely exceeded 0.5 db with a maximum of about 0.2 db assignable to the D-region.

Warwick and Zirin[11] analysed the diurnal variation of cosmic noise of 18 Mc/s at Colorado. Their absorption data did not allow them to separate the D-region absorption from the absorption produced by other layers of the ionosphere.

Therefore they used the absorption recordings to study the electron-density of the D-layer as a function of local time and height of the D-region and derived the vertical distribution of the ionizable constituent, which is supposed to be nitric oxide. From these studies, Warwick and Zirin came to the conclusion that the recombination coefficient within the D-region was either constant or increased with height.

In high latitudes, Little and Leinbach[12] have been working on 65 and 30 Mc/s in Alaska. This work is still in progress and is mainly concerned with polar blackouts associated with geomagnetic storms and visible auroras. Little and Leinbach[12] have devised an instrument called a riometer (relative ionospheric opacity meter). They have discovered the interesting phenomenon of "Pre-SC polar cap blackout", which is caused by low-level ionospheric ionization produced by low energy cosmic rays emitted by the sun at the time of some flares. These particles are of intermediate energy between primary cosmic rays and the particles responsible for geomagnetic storms and arrive at the earth within a few hours after the onset of the solar flare.

In tropical latitudes, the study of ionospheric absorption of radio waves has not received much attention. There are only a few observations made with conventional pulse-techniques at Singapore, Ibadan and Delhi. Until quite recently, no observations on the measurement of ionospheric absorption using extra-terrestrial radio noise were made in low latitudes.

4 - SCOPE OF THE THESIS

Using the opportunity of the IGY, the Department of Atmospheric Physics of the Physical Research Laboratory, Ahmedabad (Lat.23°02'N, Long.72°38'E), India, which had been maintaining an ionospheric research station at Ahmedabad, started ionospheric absorption measurements using cosmic radio noise on 25 Mc/s as the extra-terrestrial source of radio waves.

The cosmic radio noise recording equipment on 25 Mc/s was designed and constructed by the author in 1958 under the guidance of Professor K.R.Ramanathan and has been maintained to date without any serious gaps. The records have proved very valuable for studying various aspects of ionospheric physics. Among the problems studied are :

a) the diurnal and seasonal variations of total ionospheric attenuation; and its analysis into a daytime component and a component associated with the F-layer,

b) sudden ionospheric disturbances (SID's) associated with solar flares. These show up as sudden cosmic noise absorptions on the cosmic noise recordings (SCNA's), and

c) changes in the ionospheric attenuation during geomagnetically disturbed periods.

The thesis embodies the results of the study of the above-mentioned features obtained from cosmic noise records of Ahmedabad collected during the years 1956 to 1959, a period of high solar activity. Some of the points that have emerged from these studies have been published[14,15,16,17,18].

The second chapter contains a brief background discussion of ionospheric absorption and an outline of the methods of measuring absorption and summary of the results of measurements of ionospheric absorption obtained with different-techniques. In the third chapter, the experimental setup at Ahmedabad is described. The subsequent three chapters are devoted to the presentation and discussion of the experimental results.

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CHAPTER II

GENERAL DISCUSSION OF IONOSPHERIC ABSORPTION

1 - THEORY OF IONOSPHERIC ABSORPTION

The ionosphere contains free electrons and ions which are set in motion by the passage of an electromagnetic wave. The ions being more massive, their movements can be neglected in comparison with those of electrons. If each electron is assumed to be entirely free, so that its movement under the influence of the wave is uninterrupted, it will execute regular periodic oscillations so long as the wave is passing. The system is wattless; i.e. on the whole, no energy is absorbed from the wave. The oscillating electrons however scatter some of the incident radiation and the scattered wavelets add up with the incident radiation causing a change of phase of the transmitted wave and hence a retardation. The intensity of the incident waves undergo some attenuation due to scattering. On the whole no net work is done on the electron, as the electron re-radiates what it receives. If, however, the electrons are not entirely free, they collide with the molecules and ions which are present in the ionosphere and in doing so they change the ordered energy of oscillatory motion which they acquire from the electromagnetic wave, into the kinetic energy of random movement. The energy is then lost from the point of view of wave and the latter therefore becomes attenuated. The overall attenuation per unit length of the path will depend upon $N\nu$ and ω where N is the electron concentration ν, the collisional frequency of the electron and ω, the angular frequency of the wave. If ω is very much larger than ν, then attenuation decreases as the frequency increases. N and ν are functions of height and the absorption per unit length of path at any height depends directly on the product $N\nu$.

2 - ABSORPTION COEFFICIENT 'K'

Magneto-ionic theory shows that, provided the direction of phase propagation is not perpendicular to the magnetic field, the absorption coefficient is given by the expression

$$K = \frac{2\pi e^2}{mc} \cdot \frac{1}{\mu} \cdot \frac{N\nu}{\nu^2 + (\omega \pm \omega_L)^2} \qquad \ldots(1)$$

where c is the velocity of electromagnetic waves in vacuo,
e and m are the charge and mass of the electron,
ω is the angular frequency of the wave,
ω_L is the angular gyro-frequency corresponding to the longitudinal component of the earth's magnetic field.
The positive sign refers to ordinary wave and negative sign to extraordinary wave.

a) DEVIATIVE ABSORPTION

If ω is large compared with ω_L, the influence of the earth's magnetic field may be neglected and the absorption coefficient may be written.

$$K = \frac{2\pi e^2}{mc} \cdot \frac{1}{\mu} \cdot \frac{N\nu}{\nu^2+\omega^2} \qquad \ldots(2)$$

Further, if $\nu^2 << \omega^2$, then equation (2) becomes

$$K = \frac{2\pi e^2}{mc} \cdot \frac{1}{\mu} \cdot \frac{N\nu}{\omega^2} \qquad \ldots(3)$$

where $\mu^2 = 1 - \frac{4\pi Ne^2}{m\omega^2}$ ...(4)

Combining equations (3) and (4), we get

$$K = \frac{\nu}{2c}\left(\frac{1}{\mu} - \mu\right) \qquad \ldots(5)$$

Equation (5) shows that the absorption index K and the total absorption $\int K\,ds$ will depend critically on the value of the refractive index μ. Since the bending or deviation of a group of waves is also governed by the value of the refractive index, this type of absorption is termed Deviative Absorption.

b) NON-DEVIATIVE ABSORPTION

When $\mu \approx 1$, then equation (1) takes the form

$$K = \frac{2\pi e^2}{mc} \cdot \frac{N\nu}{\nu^2 + (\omega \pm \omega_L)^2} \qquad \ldots(6)$$

If $\nu^2 \ll (\omega \pm \omega_L)^2$, then the total non-deviative absorption may be written

$$\left(\int K\,ds\right)_{\mu \doteq 1} = \frac{2\pi e^2}{mc} \cdot \frac{1}{(\omega \pm \omega_L)^2} \int N\nu\,ds \qquad \ldots(7)$$

The above expressions apply only to the so-called "quasi-longitudinal" propagation of waves of angular frequency much greater than the collision frequency of electrons.

c) COLLISION FREQUENCY OF ELECTRONS WITH NEUTRAL PARTICLES AND IONS

If the average velocity v_e of the electrons is known, the average ν_{en} of their collision with neutral particles is given by the relation

$$\nu_{ea} = v_o / l_a \qquad \text{...(8)}$$

where $l_a = (\pi r_a^2 \ n_a)^{-1}$

where r_a = radius of molecule

n_a = number density of atoms or molecules.

From gas-kinetic theory,

$\frac{1}{2} m \ v_o^2 = (3/2)KT$

or $v_o = (3KT/m)^{\frac{1}{2}}$

$$\therefore \nu_{ea} = \pi r_a^2 \ n_a (3KT/m)^{\frac{1}{2}} \qquad \text{...(9)}$$

For levels below 100 km where the air is not appreciably dissociated, Nicolet[19] has given the formula

$$\nu_{ea} = 5.4 \times 10^{-10} \ n_a \ T^{\frac{1}{2}} \qquad \text{...(10)}$$

At higher levels, r_a will get smaller owing to the dissociation of oxygen and nitrogen. The motion of an electron is influenced by the presence of ions at a much greater distance, because the Coulomb forces between charged particles increases at a much more rapid rate when they approach each other. It has been shown by Cowling[20] and Nicolet[19] that the collision frequency of an electron with a positive ion is given by the relation

$$\nu_{e+} = (34 + 8.36 \log_{10} T^{3/2}/n_e^{\frac{1}{3}})\ (1 + \lambda)n_e\ T^{-3/2} \quad \ldots(11)$$

where λ is the ratio of negative ions and electrons.

In most parts of the ionosphere, λ can be neglected in comparison with 1 and n_i can be taken to be equal to n_e. The equation (11) then becomes

$$\nu_{e+} = (34 + 8.36 \log_{10} T^{3/2}/n_e^{\frac{1}{3}})\ n_i\ T^{-3/2} \quad \ldots(12)$$

3 - INFLUENCE OF NON-DISSIPATIVE PHENOMENA

Theoretically, ionospheric absorption can be measured by studying the changes in the amplitudes of radio waves reflected from the ionosphere, but absorption is not the only cause of variability of the measured amplitude. Changes due to other processes may often exceed those due to ionospheric absorption. The main non-dissipative phenomena which may influence amplitude-measurements are : (a) Polarisation, (b) Unevenness and curvature of the ionosphere and (c) Scattering by ion and electron clouds.

4 - METHODS OF MEASURING IONOSPHERIC ABSORPTION

There are three main techniques for studying ionospheric absorption :

a) Measurement of the amplitudes of signals reflected from the ionosphere,

b) study of the minimum frequencies at which echoes can be obtained in ionospheric soundings, and

c) study of radio noise from constant extra-terrestrial sources.

We shall restrict ourselves to the discussion of method (c).

(c) EXTRA-TERRESTRIAL RADIO WAVES AND IONOSPHERIC ABSORPTION

Until quite recently, the normal method of investigating ionospheric absorption was to measure the strength of man-made signals reflected from the ionosphere. Such a method, in essence, measures the total attenuation undergone by radio signals in their path from the transmitter to the receiver and includes contributions due to divergence of beam, partial reflections, polarisation effects, collision losses, losses due to scattering and deviative absorption. The use of extra-terrestrial radio waves for the study of the changing transparency of the ionosphere has certain important and useful features. These are : the constancy of the source, the relative simplicity of the equipment since no transmitters are required, and the fact that radio waves from the galaxy traverse the whole ionosphere instead of only the region below the level of reflection or scattering. Moreover, if frequencies well above the critical frequency are used, the absorption can be measured even when it is very much increased as during SID's associated with solar flares and polar blackouts. The use of frequencies well above the gyromagnetic and critical frequencies has the advantage that uncertainties arising from polarisation effects and deviative absorption are much reduced. But the exact level at which the absorption takes place cannot be determined.

The cosmic-noise method of measuring ionospheric absorption was first used in 1953 by Mitra and Shain[9]. They compared the signal strength of extra-terrestrial radio waves actually received on a fixed receiving system under different ionospheric conditions with the signal strength received on the same system at the same sidereal time under conditions of negligible absorption.

(i) The simplest equipment capable of absorption measurements by the "Cosmic-noise" method consists of a receiver connected to an aerial by means of a transmission line and a pen-recorder to measure the noise power of the receiver output. Calibration is done by means of a constant noise generator. This system is susceptible to variations of receiver gain, and it is therefore necessary to use electronically stabilised a.c. and d.c. power supplies for the receiver.

(ii) Little and Leinbach[13] devised an instrument called a riometer (relative ionospheric opacity meter) which is a sensitive, self-balancing noise-measuring equipment. The riometer incorporates sweep-frequency and minimum-signal detector circuits in conjunction with the receiver. The riometer registers the minimum noise level as a 6 Kc/s exploring band is swept across at the rate of 2.5 Kc/s through a 100 Kc/s search band. The sweep-frequency minimum-detector technique was previously used by Lee[22] in a total-power cosmic-noise receiver.

<u>Advantages of the riometer</u> : The riometer has three important advantages over a simple total-power type receiver. (1) It provides a linear input/output characteristics. (2) The equipment is capable of operating with high accuracy in the presence of narrow band R.F. interference and (3) the equipment possesses good long-term stability since receiver acts as a null-detector rather than as an amplifier.

5 - SUMMARY OF RECENT EXPERIMENTAL RESULTS OF IONOSPHERIC ABSORPTION

a) FREQUENCY DEPENDENCE

Piggott[21], Appleton and Piggott[23] and Allcock[24] have carried out a detailed analysis of observations extending over a number of years at stations in England. They find that the variation of absorption with the inverse square of frequency, as predicted by theory is generally valid. Expressing the absorption in the form

$$-\log \rho = \frac{A}{(\omega \pm \omega_L)^2}\ ,$$ the factor A for southern England (where $f_L = \omega_L/2\pi = 1.2$ Mc/s) comes out to be 505 db. This value is subject to considerable enhancement at frequencies near the critical frequencies of E and F layers where the deviative-type absorption comes in play.

At Ibadan (lat. 7°23'N, long. 3°54'E), Skinner and Wright[25] found that non-deviative absorption was proportional to the inverse frequency instead of to inverse square of the frequency. A similar frequency dependence was noticed at Singapore.

b) REGION OF PRINCIPAL ABSORPTION

Bracewell and Straker[26] observed sudden phase anomalies in the low frequency waves propagated through the D-region during an SID (Dellinger Effect). Beynon and Davies[27] showed that obliquely reflected radio signals from both E and F layers were almost identically affected by absorption changes in vertical sounding records. This implies that the absorption occurs at relatively low levels. Further Dieminger[28], Heppner[30], Gardiner and Pawsey[20] and Appleton and Piggott[23] have reported that high absorption occurs in frequent association with unusually low-lying vertical-incidence sounding echoes of a sporadic nature from the height interval 65 to 90 Km.

These facts leave little doubt that a large part of the non-deviative absorption is due to excess ionization in the regions below the normal E layer.

Evidence that there is nevertheless appreciable absorption ascribable to higher regions was obtained by Mitra and Shain[9] and Bhonsle and Ramanathan[15], who found a correlation between total attenuation of cosmic radio noise and f_oF_2, when the value of f_oF_2 exceeded a certain minimum.

c) SOLAR CONTROL

More than one agency can be responsible for the production of ionization in the D-layer. On the average, however, there are regular diurnal and seasonal variations of absorption depending on the cosine of the sun's zenith angle through a relationship of the form

$\alpha = \alpha_0 (\cos \chi)^n$ where α_0 is the maximum or noon-time absorption.

Taylor[21], Appleton and Piggott[23], and Rawer[22] have shown that the exponent is definitely smaller than the theoretical value of 3/2 derived by Appleton. The exponent varies with season, latitude and with sunspot cycle, but with anomalies which lead to the conclusion that something more than solar radiation is involved for the absorption. Davies and Hagg[33], for example, have analysed the absorption effects at Prince Rupert (54.3°N, 130.3°W) and find that the exponent 'n' expressing the influence of solar radiation comes down to a value of about 0.5. This result may be compared with Piggotts[21] value of 0.75 for the observations made at Slough. At equatorial latitudes, Skinner and Wright[25] investigated the variation of $-\log \rho$ with the sun's zenith distance both diurnally and seasonally. They found that for diurnal variation

$$-\log \rho \quad \propto \quad (\cos \chi)^{n}$$

where n is about 0.7. However, from the seasonal variation of the monthly means of the noon values of $-\log \rho$, they obtained much higher value of 'n'. In 1953-54, they found that 'n' was about 2. The seasonal high values of $-\log \rho$ at Singapore and Ibadan remain in a class apart.

d) VARIATION OF $-\log \rho$ WITH SUNSPOTS

Lange-Hess[34] has investigated the relation of absorption to sunspot number at several latitudes and has found that there is a close relationship in equatorial regions and in high latitudes, but that they are quite irregular at Slough in winter. Appleton and Piggott[23] have shown that for any one calendar month, over a series of years, the noon value of 'A' varies nearly linearly with the annual mean sunspot number R i.e.

$$A_{noon} = \alpha + \beta R.$$

Both α and β are least in winter and greatest in summer. α increases from 230 in December to about 350 in July and β from about 2 in mid-winter to 3 in midsummer.

e) WINTER ANOMALY

Appleton and Piggott[23], from their studies of the seasonal dependence of $-\log \rho$ on $\cos \chi$, have confirmed the existence of a "Winter Anomaly" in the months November to February eversince the series of observations started in 1935. The winter anomaly is characterised by the occurrence of excessive absorption on certain groups of days during the winter. A statistical study showed that the occurrence of these days of high absorption was correlated with the occurrence of sporadic reflecting strata below the level of E layer. Dieminger[23] found that the days of high absorption were often associated with weak reflections from low heights of the order of 75 to 95 Km. Appleton and Piggott[23] attempted to find if days of high absorption and periods of magnetic activity were connected but could not find any correlation. They suggested that either an additional ionizing source was present or some agency was operative which caused a redistribution of ionization which caused an increase in the integrated value of $N\nu$ within the absorbing stratum.

A comparison of Slough, Singapore and Falkland Islands data showed that no anomalous behaviour was evident at Singapore at any time during the year, but that it occurred at Falkland Islands in the local winter. They concluded that the phenomenon was connected with low cos χ conditions and not to change in the intensity of solar radiation.

Morris[35] reported on the anomalous winter midday absorption of cosmic radio waves of 24.3 Mc/s at Cambridge. He concluded, from the data collected from January 1957 to May 1958 that the average midday absorption in winter (December and January) was about twice as great as that in summer (June and July). This could not be adequately explained in terms of changes in F_2 critical frequency. According to him, this anomalous absorption can be explained, if one assumes that $\nu^2 \ll (\omega+\omega_L)^2$ in summer and on 'normal' days in winter, but that on abnormal days $\nu \simeq \omega+\omega_L$. This suggestion implies that on some days in winter, which are of the abnormal type, absorbing electrons are found in abnormally large numbers near the level where $\nu \simeq \omega+\omega_L = 2.6 \times 10^7$ sec^{-1}, that is, at a height of about 60 km.

6 - HIGH LATITUDE ABSORPTION EFFECTS

Little and Leinbach[12] have studied the radio absorption characteristics of the Arctic ionosphere using 30 Mc/s extra-terrestrial radio waves. Their observations have shown that regions of anomalous high latitude absorption have typical lateral dimensions in excess of 100 km and that marked differences can occur during disturbed periods between stations 300 km apart. Almost all the absorption occurs below the E region. The absorption correlates well with local geomagnetic K-index and is apparently associated with the bombardment of the upper atmosphere by corpuscular streams which produce the auroras.

Reid and Collins[36] have studied cosmic noise absorption on 30 Mc/s at Ottawa and Churchill, and shown the existence of two apparently distinct types of abnormal absorption events apart from sudden cosmic noise absorptions (SCNA's) associated with solar flares. One of these (Type II) is predominantly a night-time phenomenon and closely associated with auroras and geomagnetic disturbances. When type II (auroral) absorption occurs at Churchill, it does not necessarily occur at Ottawa, but occurrence at Ottawa always seems to be accompanied by occurrence at Churchill. The magnitude of absorption can be as high as 9-10 db only for short periods.

Chapman and Little[36] have suggested mechanism to explain type II (auroral absorption) by an increase in ionization in the lower ionosphere due to bombardment of electrons of solar origin and their associated Bremsstrahlung radiation.

Another type of high-latitude absorption (Type III) is confined to polar latitudes. The cosmic noise recordings of this type of absorption are much more uniform in appearance than recordings of the auroral absorption (Type II) described above, and the magnitude of the absorption is much greater during day than during night. It is closely correlated with great solar activity and is very similar to the absorption events described by Bailey[31] which occurred in polar latitudes following the great solar flare of 23 February 1956. This type III (high-latitude) absorption appears to set in within a few hours of the onset of a major solar flare and usually persists 2-3 days, gradually declining in intensity during this period. This absorption is predominantly a daytime phenomenon; in contrast to type II (auroral absorption).

Reid and Leinbach[37] have reported on 24 type III (high-latitude) events. More recently, they named them as "Pre-30 Polar Cap Blackouts". They attribute this ionospheric absorption in Arctic regions to low-energy cosmic ray protons associated with solar flares. Confirmation of proton theory has come from Balloon observations of cosmic-rays over Fort Churchill by Anderson and others[38] during a type III event and later by University of Minnesota and State University of Iowa groups on August 22, 1958. These observations showed the presence of a flux of protons at balloon heights whose energies were not high enough to allow them to penetrate to ground level.

The normal sequence of events is as follows :

(1) A major solar flare occurs, usually accompanied by a short-wave fade-out over the sunlit hemisphere of the earth. The fade-outs and the associated SCNA are caused by e.m. radiation from the flare.

(2) The flare is followed by a strong low frequency solar radio noise storm which lasts for several hours.

(3) Within a few hours after the flare the type III absorption begins over the entire polar cap, the actual onset often being obscured by solar noise storm; the absorption reaches a maximum within a few hours, then decays slowly during following few days.

(4) After a day or two a SC-magnetic storm occurs, accompanied by ionospheric disturbances.

CHAPTER III

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CHAPTER III

25 Mc/s COSMIC RADIO NOISE RECORDING EQUIPMENT AT AHMEDABAD

1 - GENERAL DESCRIPTION

Fig.1 shows the block diagram of cosmic radio noise recording equipment, designed and constructed by the author as part of the research programme in ionospheric physics in the Physical Research Laboratory, Ahmedabad.

It is a total-power type radiometer operated on 25 Mc/s on the lines of the instrument used by Shain and Mitra[9] for their work on ionospheric absorption on 13.3 Mc/s.

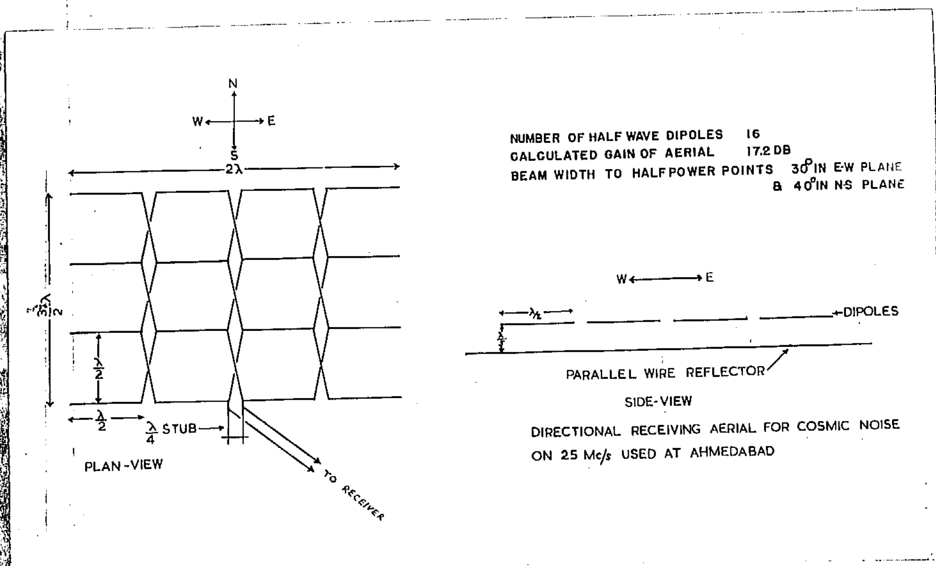

Fig.1. 25 Mc/s Cosmic noise recording equipment at Ahmedabad.

The equipment consists of a directional antenna connected to a communications-type receiver whose output, after second detection, is fed to a d.c. amplifier. After d.c. amplification, the output is recorded on a 0-1 mA recording milliammeter. The output of the receiver is calibrated manually every day against the noise generated in a pure tungsten-filament type noise diode. The filament and high tension supplies are stabilised electronically to ensure good stability. A cold resistor of 100 ohms is automatically substituted for the aerial for a period of 2 min at intervals of 45 min by means of a d.p.d.t. relay actuated by a geared-down synchronous motor. With this arrangement it was possible to make corrections for the unavoidable changes in the receiver noise level. The same cold resistor was used to load the impedance of the diode noise generator.

2 - ANTENNA

a) POWER GAIN OF A HALF-WAVE DIPOLE

Even the simplest aerial, the Hertzian dipole, radiates more energy in certain directions than in others; and a half wave aerial is still more directional. In discussing the directional characteristics of aerials, it is usual to express the degree of beaming in terms of the power gain. The absolute power gain of an aerial is defined as its gain over a perfect all round isotropic radiator. Such a radiator is a purely theoretical concept and cannot be realised in practice, since owing to the transverse nature of e.m. waves, it is impossible to devise a source which radiates uniformly through a complete solid angle 4 π. However, for purposes of calculation it provides a satisfactory standard. The absolute power gain of a Hertzian dipole is 1.5, while that of a half-wave aerial is somewhat higher having a value of 1.64.

b) RECEIVING AERIALS

According to the reciprocity theorem the aerial has similar directional characteristics for both transmission and reception. The energy delivered to the receiver is abstracted initially from the incident e.m. waves. It is evident, however, that the whole of this power cannot be delivered into the receiver for during the absorption process an alternating current is set up in the aerial, and this inevitably gives rise to a radiation field. The aerial therefore behaves partly as an absorber and partly as a scatterer of the incident radiation. It is usual to consider the collecting area S as being made up of two parts, the equivalent absorbing area S_A and, the equivalent scattering area S_S, whose sizes are such that a fraction S_A/S of incident power enters the receiver, while a fraction S_S/S is retransmitted. The relative values of S_A and S_S depend on the parameters of the circuit. The first amplifying stage of the receiver has a finite electrical resistance which causes an impedance to the flow of current between the input terminals. If this impedance is very high the amplitude of the current in the dipole will be small and S_A and S_s will both tend to zero. If, on the other hand, this impedance is so low as to approximate to a short circuit, the value of S will tend to become maximum, but almost all the power will be reradiated, so that while S_s will be large. S_A will be again very small. For any receiving system, there is an optimum condition between these two extremes for which the power transfer into the receiver is maximum. When the input resistance of the receiver is matched to this value, the system is said to be matched. It can be shown that when the incident radiation falls on to a matched aerial from the best direction of reception $S_A = S_s = G\,\lambda^2/4\pi$ where G is the absolute power gain. If the input terminals of the aerial are short circuited, $S_A = 0$ while $S_s = G\,\lambda^2/4\pi$. For a matched half-wave aerial $S_A = 1.64\,\lambda^2/4\pi$.

c) DIRECTIONAL AERIAL USED FOR COSMIC NOISE MEASUREMENTS ON 25 Mc/s AT AHMEDABAD

Fig.2 shows a schematic diagram of the directional aerial used by the author in conjunction with a communications receiver for the cosmic radio noise observations on 25 Mc/s at Ahmedabad. It is a broadside collinear array consisting of 16 half-wave dipoles spread in E-W direction in 4 rows and 4 columns. The aerial is backed by a parallel wire reflecting screen stretched along the ground at a distance of 0.2 wavelength from the dipole elements. This increases the gain of the antenna by a factor of 2 and maintains constant reflectivity in spite of changing meteorological conditions. The aerial is directed vertically upwards. For a broadside-collinear array of this type a spacing of 0.5 λ between adjacent rows is particularly convenient since the right phase relationship is easily obtained by the feeder lines; also the total impedance is easy to estimate since the elements are all in parallel. The beam width of an aerial array to half-power points is approximately given by 60 λ/a in degrees, where a = length of the array in terms of wavelength. In the case of our antenna, the length in E-W direction is 2 λ and the width is 3 λ /2. This means that,

Photo missing

Fig.2. Schematic diagram of the directional aerial.

the beamwidth of our aerial to half power points is about 30° in E-W and 40° in N-S planes. The power gain of an array over a single dipole is equal to the number n of half-wave aerials and the absolute gain, G, is equal to 1.64 x n. If a conducting screen is placed behind the screen, the whole energy is concentrated in one direction and the gain is increased by a factor of 2 for a separation of 0.2 λ between dipoles and reflecting screen. The absolute gain of the array then becomes 3.28 x n. The power gain of the broadside-collinear array used at Ahmedabad is thus equal to 3.28 x 16 = 52.48 or 17.2 db. over an isotropic radiator.

The impedance of a thin full-wave dipole fed at the centre is about 2000 ohms, hence four full-wave dipoles in parallel give an impedance of about 500 ohms (balanced). It should be noted that the antennae may be considered to be in parallel, since they are spaced at intervals of $\lambda/2$ along the feeder; also the feeder is twisted round between each full-wave dipole so as to obtain correct phase relationship for broadside radiation. The problem remains of matching the aerial impedance of 500 ohms to the transmission line whose characteristic impedance is 95 ohms, and the transmission line impedance to the receiver input impedance which is of the order of 100 ohms (balanced). The transmission line used for connecting the aerial to the receiver was a shielded twin-wire solid-dielectric low-loss radio frequency cable whose Z_0 = 95 ohms. This could be directly matched to the receiver input impedance. The transmission line was matched to the aerial impedance of 500 ohms in the following manner : A quarter wave stub of twin-wire, shorted at the far end was connected in parallel with the aerial feed points and the optimum position for connecting the transmission line to the stub was found by sliding it along the length of the stub. The total length of the cable between the aerial and receiver was about 50 feet.

3 - RECEIVER : ITS FUNCTIONS AND LIMITATIONS

The purpose of the receiver is to convert the minute signals delivered to it by the aerial into a form capable of actuating the output meter. For the measurement of solar and cosmic radio waves, this requires a high degree of amplification. Since the output is usually recorded on a recording milliammeter, some amplification is done at the signal frequency but it is usual to employ the superheterodyne system in which the greater part, or all the amplification occurs at a lower frequency known as the intermediate frequency. The intermediate frequency signal is then rectified to produce a unidirectional signal. A rectifier is a nonlinear device and its output is not in general simply related to the input. It is, therefore, necessary to rely on calibration to establish the significance of a given reading in the output meter. The rectified signal is smoothed, partly by circuit arrangements and partly by the output meter.

The resultant smoothed signal, which is relatively constant, is what is indicated on a receiver output meter. If the changes in output are not sufficiently prominent on the record, further amplification (d.c. amplification) may be employed. The usual method is to amplify the difference between the detector output voltage and a suitable steady comparison voltage. Since both receiver noise and cosmic and solar noise have random waveforms, the powers are additive and the desired signal is only recognisable through the increase in the mean level which it causes. In normal radio practice signals much greater than the receiver noise level are common, though in some applications signals right down to noise level are utilised. The receivers used in radio astronomy may be required to operate with much smaller input powers. There, the wanted signal is commonly only a small fraction of the noise generated within the receiver itself.

The sensitivity of a receiver is not limited by any inability to obtain more amplification but by electrical noise generated in its valves and resistors. The excellence of a receiver in respect to the generation of internal noise is specified by either of two parameters : by the "noise factor" N or by the "noise temperature", T_N. We define gain factor, "g" in terms of the differential ratio of output P to input p i.e. $g = dP/dp$ and shall take P as the power delivered to the detector and p as the available power at the aerial terminals. Now for a given input power p, the output is greater than gp because of the noise generated in the receiver, say $P = g(p + p_r)$, where p_r is the receiver noise referred to the input terminals. It simply adds to p since it is a random noise. Both the noise factor and the noise temperature are essentially measures of p_r in terms of thermal agitation. The receiver noise temperature T_R which is a direct measure of p_r is obtained by writing $p_r = K\,T_R\,\Delta f$ where K is Boltzmann's constant (= 1.37 x 10^{-23} Joules per deg.) and Δf is the integrated noise acceptance band of the receiver. The noise temperature, so defined, is simply the effective temperature of an aerial which would yield as much noise as the receiver generates.

The noise factor is a ratio relating p_r to the available power from an aerial at ambient temperature T_0. In this case,

$$p = K\,T_0\,\Delta f.$$

N is defined by

$$N = \frac{\text{Total noise power}}{K\,T_0\,\Delta f} = \frac{K\,T_0\,\Delta f + p_r}{K\,T_0\,\Delta f}$$

Therefore $p_r = (N - 1)\,K\,T_0\,\Delta f.$

and $T_R = (N - 1)\,T_0.$

To give an idea of the orders of magnitude for a typical receiver, Δf = 1 Mc/s, and N = 10, for T_0 = 300 deg.Kelvin so that $p_r \doteq 4 \times 10^{-14}$ watts and T_R = 2700 deg.

a) RECEIVER USED FOR RECORDING COSMIC RADIO NOISE ON 26 Mc/s AT AHMEDABAD

A Hammarlund Super-Pro Receiver, Model SP-400-SX, was adapted for cosmic radio noise work on 26 Mc/s at Ahmedabad. It is an 18-tube superheterodyne receiver originally meant for amplitude-modulated (AM) or continuous wave (CW) code signals within the range 1.250 to 40 Mc/s. This coverage is obtained in five-selected bands. An extremely wide range of selectivity is provided by a variable-selectivity crystal filter and variable-selectivity I-F transformers. Either manual or automatic sensitivity control can be selected and a noise limiter circuit is provided.

(i) Antenna Circuit : The antenna is coupled to grid of the 1st R-F amplifier through an input transformer having an untuned primary and tuned secondary. The terminals of the primary coils are ungrounded. This symmetrical arrangement of antenna primary coils permits full advantage to be taken of the noise reducing properties of a balanced transmission lines lead-in. The impedance of the input circuit is approximately 100 ohms.

(ii) R.F. Amplifiers : There are two conventional grounded cathode stages of R.F. amplification preceding the first detector or mixer.

(iii) H.F. Oscillator : The H.F. Oscillator operates at a frequency 465 Kc/s lower than the signal on 20-40 Mc/s

(iv) Mixer : The 1st detector or mixer employs a 6L7 pentagrid mixer. Its injection grid (grid No.3) is coupled to the H.F. oscillator cathode and its signal grid (grid cap) is coupled to the plate of second R.F. amplifier tube by means of a second R.F. transformer.

(v) I.F. Amplifier : The intermediate frequency amplifier has three stages consisting of three coupling transformers and three pentode amplifier tubes of the remote cut-off or super-control type. The first two transformers are identical and have tuned primaries as well as tuned secondaries. The secondary coils are fixed in position, while the primary coils are mounted on sliding rods permitting them to be moved back and forth with respect to secondaries, thus changing the degree of inductive coupling between them.

(vi) Second detector : The second detector is a small twin diode operated with both plates and both cathodes connected in parallel.

The following tubes are used in the circuit :-

Valve type	Function
6K7	1st and 2nd R.F. amplifier, and 1st I.F. amplifier.
6L7	Mixer.
6J7	H.F. oscillator.
6SK7	2nd and 3rd I.F. amplifier.
6H6	2nd detector.

The above is the description of the relevant portions of the Hammarlund receiver.

b) CHANGES MADE IN THE ORIGINAL CIRCUIT OF THE RECEIVER

The following alterations or additions were made in the original circuit to adapt the above receiver for cosmic-noise work :

(i) Since only R.F., Mixer, I.F. and 2nd detector stages were utilised for amplification and detection of cosmic radio noise, it was convenient to divide the receiver circuitry into two parts. Circuitry from antenna terminals to the 2nd detector formed part (1). Part (2) included the remaining circuits such as audio amplifiers, AVC, BFO, Noise Limiter etc. Of these audio section was used to identify aurally the interference due to man-made or natural signals. AVC and BFO circuits were not used at all.

(ii) Since the original AC and DC power supplies were unregulated, a highly stabilised high tension supply unit for plate, screen and bias voltages was built. Mains supply for these supplies was taken through a constant voltage transformer.

(iii) Filaments of the valves from 1st R.F. to 2nd detector, which were originally in parallel, were connected in series and the filament heating power was taken from a separate stabilised d.c. supply of 63 volts. All these valves require heater current of 300 mA.

(iv) The output was taken after second detection across its load resistance and fed to a d.c. amplifier for further amplification.

(v) Since pulsed transmitter of ionospheric recorder and the present equipment were installed in the same hut, to avoid their interaction, an arrangement was made to paralyse the receiver and shorting the recording milliammeter for the duration of transmission.

(vi) A one revolution per minute synchronous motor was geared down to perform one revolution per 45 minute and it operated a d.p.d.t. relay to replace the aerial periodically by a cold resistor of the same impedance as that of a matched aerial. This cold resistor is also used as a load for the noise-diode.

c) OPERATING CONDITIONS OF THE RECEIVER

Control	Setting
Plate voltage	250 Volts.
Screen "	103 "
Bias "	-50 "
Filament "	+63 "
Bandwidth	5 Kc/s
AVC or Manual	Manual
Crystal select	Off
Phasing	On arrow
Limiter	Off
Sensitivity	10
AM or CW	AM

4 - DESCRIPTION OF DIODE NOISE GENERATOR

The complete radiometer includes a standard noise source which could be connected in the place of the aerial and used to calibrate the receiver output. This source may be a standard signal generator or a so-called "noise generator", of which there are two common forms, the variable temperature resistor and the saturated diode. The noise generator has the marked advantage over the signal generator that the spectrum over a small interval is identical with that of the waves to be measured. Thus the form of the frequency response of the receiver does not affect the relative readings. In each case the impedance of the calibrating source is made identical with that of the aerial so that the receiver operates under identical conditions. The most direct way of using the calibrating source is to calibrate the receiver output directly at suitable levels.

The noise source in most general use is the temperature limited diode in which the anode current has a random or noise component i_n given by

$\overline{i_n^2} = 2e\,IB$, where e is the charge of an electron, I is the anode current and B is the bandwidth. If i_n flows through R, the noise power available from the terminals of the resistance, additional to its thermal noise is therefore

$$(\tfrac{1}{2}\, i_n)^2 R = \frac{e\,I\,B\,R}{2} .$$

The impedance of the diode is in parallel with R but is usually of the order of at least 20,000 ohms in normal circumstances. If R corresponds to the aerial impedance, $\frac{1}{2}$ e I B R can be substituted for P_s in the equation

$$N_F = \frac{P_s}{n\,K\,T\,B} \quad \text{where } P_s \text{ is the noise power required}$$

to double the receiver noise.

Taking $T = 290^\circ$ and $n = 1$, we have $\frac{e}{2\,n\,K\,T} = 20$

and the noise factor is given by $N_F = 20\,I\,R$, I being in amperes and R in ohms. Alternatively expressed in decibels

$$N_F = 10 \log_{10} 20\,I\,R.$$

I is adjusted by varying the filament current and an important point to be remembered is that the anode voltage must be sufficient to ensure that the current remains temperature-limited even at the maximum value required. Failure to attend to this point usually reveals itself by a decrease of noise with increase of anode current. Oxide-coated cathodes are unsatisfactory under temperature-limited conditions. Thoriated filaments have been used successfully but it is safest to employ pure tungsten.

Fig.3 shows the circuit arrangement of the balanced noise generator constructed by the author, using a Marconi type CV-172 pure tungsten filament noise diode, to calibrate daily the cosmic noise recordings on 25 Mc/s at Ahmedabad. It has been mentioned previously that there is a provision to substitute the noise generator instead of the aerial by means of a d.p.d.t. relay. The output impedance of the noise generator is 100 ohms balanced, same as the aerial impedance. The noise-diode assembly and its power pack are built on two separate chassis and a d.c. milliammeter is incorporated to measure the diode plate current in the power supply circuit. Since the noise-diode is operated under temperature limited condition, the filament voltage is adjusted for changing d.c. plate current from 0 to 25 mA in steps of 5 mA by means of a rheostat in series with the primary of the filament transformer. The mains-supply is taken through a constant voltage transformer.

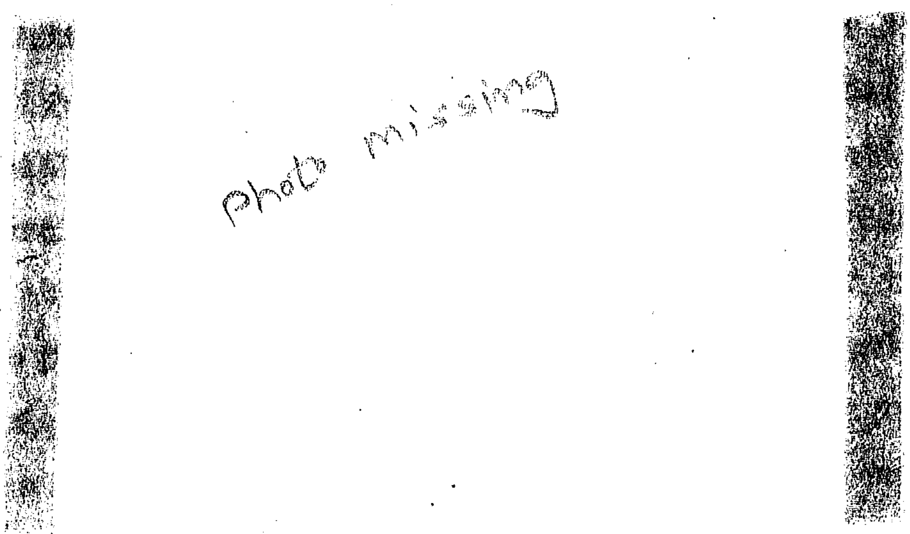

Fig.3. Balanced noise generator used for calibrating cosmic noise recordings on 25 Mc/s.

The rated maximum anode current for CV172 is 30 mA but higher currents for short periods are allowed if some reduction of the valve life is acceptable. The filament voltage for CV172 should not exceed 7 volts. A safe plate voltage to ensure saturation upto 50 or 60 mA is 100 volts.

5 - DESCRIPTION OF D.C.AMPLIFIER

In a direct coupled amplifier, the input, output and interstage couplings are conductive i.e. they are either direct connections or resistive networks. No "blocking" condensers or coupling transformers are employed. Thus d.c. signals may be amplified, whereas the bandpass characteristics of other types of amplifiers drop to zero gain at zero frequency. The fact that the conductive coupling must be used throughout, results in several special problems of design and stability. One obvious design problem arises because plate potentials are considerably higher than grid potentials. It is therefore necessary to have the cathode of a following stage at this higher potential from the ground, or to use a device to lower this potential by the correct amount. Since batteries are impractical here, a negative supply voltage and a resistance divider are generally required, with resulting decrease in gain. The "zero adjustment" problem is the most difficult one resulting from conductive coupling. If the effects of noise and pickup are neglected, a non-conductively coupled amplifier gives zero output for zero input regardless of circuit parameters such as resistor values, supply voltages and tube characteristics. This is not true of a direct-coupled amplifier; the d-c output at a given d-c input (e.g., zero) depends on all these things. A certain output current or voltage is usually required for a specified input. In order to meet this requirement some kind of 'zero' adjustment is needed to compensate for variation of the above parameters.

Fig.4 shows a high gain d-c amplifier constructed by the author for use in the cosmic radio noise recording equipment on 25 Mc/s at Ahmedabad. The output of the receiver taken after second detection is too weak to be directly

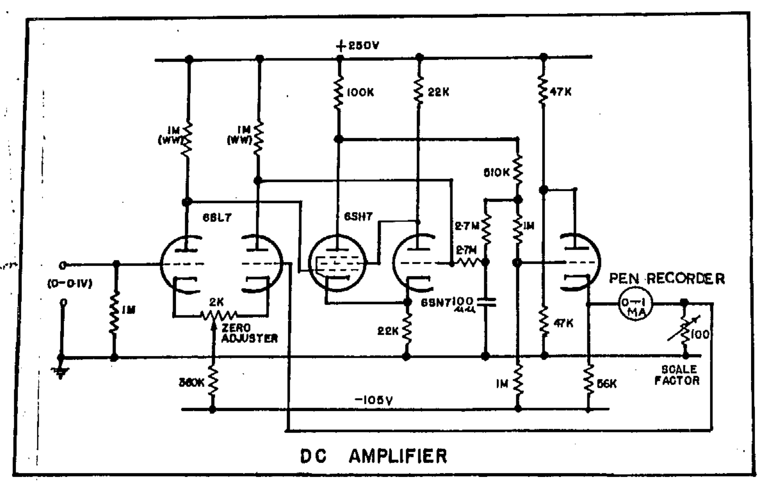

Fig.4. A high gain d-c amplifier used for amplifying the output of second detector.

recorded on a 0-1 mA recording millimmeter and hence requires d-c amplification. Current feed back is employed, the current in the meter being measured by a stable resistance and a voltage proportional to it fed back to the auxiliary grid of the input differential amplifier. The second stage is a pentode amplifier with its cathode returned to a cathode follower. This arrangement permits differential input so that the full gain of the first stage is realised. It also allows input voltages at the plate level of the first stage; therefore, no dropping divider is needed at this point where the drift of such a divider would be felt very much more than after the second stage. Another feature permitted by the cathode follower in the second stage is the local positive feedback (by means of the 8.4 megohm resistor), which increases the linearity with overall negative feedback. Connecting the pentode screen and triode plate together prevents the common dropping resistor from causing a reduction in gain; in addition, the reduction in screen voltage produces higher gain in the pentode. The output cathode follower is designed to limit the current in the 1 mA meter at about 2 mA in either direction; the two limits result from the plate current cut-off and from grid current in the input resistance. The circuit may be used for full-scale input voltage as high as 10 volts, the limit depending on the value of the feedback resistor. The lower limit of full-scale input voltage is determined by the drift of the input tube. This limit is about 100 mV, and at this scale factor the drift may be noticeable over a period of hours. In order to minimize this drift, the input tube was aged several hundred hours with the heater on. The d-c amplifier circuit described above has been found to give satisfactory service for the last four years. It has not given any special trouble except for the replacement of valves once in a few months. The only extra precaution that we have taken is to heat the filaments of d-c amplifier valves from a 6V accumulator battery instead of from filament transformer. Stability was better with this arrangement.

6 - PEN RECORDER

The output of the receiver after d-c amplification is fed to the pen recorder. It is a recording milliammeter with 0-1 mA full-scale sensitivity manufactured by Evershed & Vignoles Co., England. It has a synchronous motor drive and is operated at a chart speed of 1 inch per hour. Its time constant is of the order of 1 sec but is slightly variable with the damping arrangement provided in the instrument.

7 - NOTE ON STABILIZED POWER SUPPLIES

Considerable experience with different voltage-stabilizing circuits indicates that those of the simple degenerative-type are the most generally satisfactory. A voltage-stabilised power supply accomplishes more than simply furnishing a d.c. voltage of a fairly stable value. It affords a low source impedance, considerably reducing the interaction between various parts of a circuit for which it furnishes plate power and the stabilising circuit itself acts as an excellent filter for ripple voltages. In order to compare different power supplies, it is convenient to define the stabilization factor

$$S = \frac{E_o}{E_s} \cdot \frac{dE_s}{dE_o} \qquad \ldots(1)$$

where E_s is the mains supply voltage and

E_o is the stabilised d-c output voltage; and to define the output or source impedance,

$$R_o = -\frac{dE_o}{dI_o} = \frac{e_o}{i_o} \qquad \ldots(2)$$

where i_o is the current supplied to the load. The most interesting property of the stabilising circuit itself is expressed by the smoothing factor

$$\alpha = \frac{dE_o}{dE_1} = \frac{e_o}{e_1} \qquad \ldots(3)$$

where E_1 is output voltage of the transformer-rectifier-filter circuit preceding the stabilising circuit. It is evident that the quantities defined in the equations (1) and (2) specify the most important features of a voltage stabilised supply. The smoothing factor, defined in equation (3), enables an estimate to be made of the ripple voltage at the output, if the ripple voltage at the input of the stabilising circuit is known.

The basic circuit of most stabilised supplies of the degenerative type is indicated in Fig.5(a).

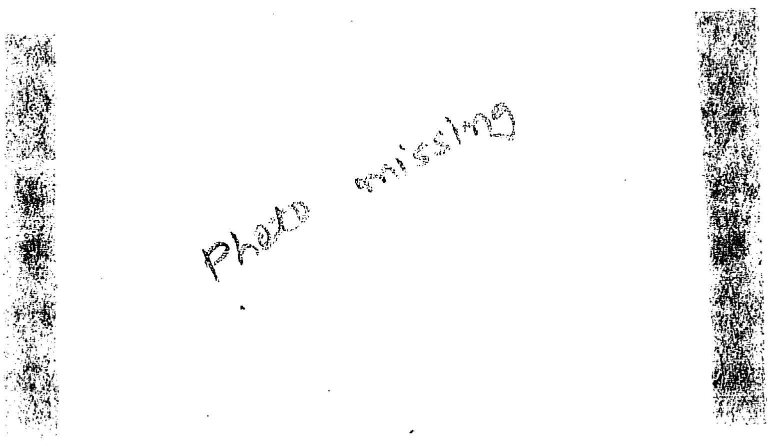

Fig.5(a). Basic circuit of a stabilised supply of the degenerative type.

Fig.5(b). A simplified equivalent circuit.

The circuit consists of a conventional transformer-rectifier-filter supply, indicated by the block T-R-F, followed by a triode connected in series with the positive supply bus. A fraction β of the output voltage is compared with a fixed voltage E, obtained either from a VR tube or from a battery of dry cells. The difference between the two voltages is amplified by a difference amplifier of gain G and is used to control the grid bias of the series triode, so as to afford a degenerative compensation for any change in circuit conditions that tends to alter the existing output voltage. All circuit voltages must be so arranged that d-c coupling can be used throughout the amplifier. Where this type of coupling results in a loss in gain, resistors can be bypassed by capacitors so that a greater degeneration is obtained for a-c signals in particular, for ripple voltages.

A simplified equivalent circuit is shown in Fig.5(b) where R_1 is the source impedance of the transformer-rectifier-filter combination, and r_p and μ are the plate resistance and the amplification factor, respectively, of the triode. By means of a simple circuit analysis, it is found that

$$S \approx \frac{R_o}{R_1} \mu \beta G \qquad \ldots(4)$$

$$R_o \approx \frac{R_1 + r_p}{\mu \beta G} \qquad \ldots(5)$$

$$\alpha \approx \frac{1}{\mu \beta G} \qquad \ldots(6)$$

when $\beta G >> 1$. In case of practical power supplies, the plate-load resistor of the final stage of the difference amplifier is often connected to the plate side of the series triode instead of to the cathode side. This arrangement is chosen in order to maintain adequate gain for the difference amplifier as the grid bias of the series triode approaches zero.

a) STABILISED POWER SUPPLY REQUIREMENTS FOR RECEIVER AND D.C. AMPLIFIER

(i) Receiver

	D.C.	
Plate voltage	250 volts	100 mA
Screen voltage	105 volts	25 mA
Bias for sensitivity control	-50 volts	15 mA
Filament voltage	63 volts	300 mA

(ii) D.C.Amplifier

Plate voltage	250 volts	35 mA
Bias voltage	-106 volts	10 mA
Filament voltage	6 volts	1.2 Amp.

These were the power supply requirements for operating the receiver and d-c amplifier of cosmic radio noise equipment at Ahmedabad. Except for filament voltages, all the remaining voltages were obtained from the same stabilised power supply constructed by the author.

Fig.6 shows the model 50 power supply circuit suitably modified to satisfy our requirements. (Elmore and Sands[43]). The model 50 supply, when delivering a current of

100 mA to an external load, it has an rms ripple voltage of 1.5 mV and presents an output impedance of 0.5 ohm for slow changes in the load. The measured stabilization factor is about 1200. The difference amplifier in the stabilizing circuit is based on the double-triode amplifier followed by a single-triode amplifier. Both plates of 6SL7 difference amplifier are biased at approximately the same potential (200 volts) to obtain a symmetry in currents and voltages between the two halves of the amplifier. It may be shown that any change in the effective contact difference potential between grid and cathode, common to both tubes of the difference amplifier, suffers a degeneration of nearly $1/\mu$ in comparison with a signal impressed on the amplifier between grid and ground. For this reason the stabilized output voltage of the supply shows very little drift when the heater voltage is varied $\pm$ 10 %. It will be noticed that the current for the VR tube is obtained from the output side of the supply. This arrangement ensures that the comparison voltage will not be subject to changes caused by a varying current through the VR tube. Another point worth noting in all the supplies is that the plate-load resistor of the amplifier stage that couples to the grid of the series triode is returned to the unstabilized side of the power supply. This enables the potential of the grid of the series triode to approach that of its cathode without causing the current through the amplifier stage to become very small and the gain, therefore, to become much reduced.

Fig.6. Modified Model 50 stabilised power supply for receiver and d.c. amplifier.

b) DESCRIPTION OF STABILISED FILAMENT POWER SUPPLY FOR THE RECEIVER

Fig.7 shows the circuit diagram of a filament power supply designed and constructed by the author to give 63 V.DC and current 300 mA. Originally the filaments of the receiver valves were in parallel and heated by means of a filament transformer. Soon it was realised that for good stability a-c heating of the filaments had to be discarded. It was essential to heat them by a well-stabilised d.c. voltage. All the filaments were connected in series. The sum of filament voltages of the valves from 1st RF to 2nd detector was 50.4 volts and the heater current was 300 mA, same for all of them. It was necessary to raise this voltage to 63 volts for the proper operation of the amplifier tube 1N5GT in the regulating circuit. The excess voltage was dropped across a suitable resistor in series with the heaters. Special heavy duty transformers and filter-chokes were wound in the laboratory and it was decided to connect six 6L6 tubes in parallel as series valves so that 300 mA current could be drawn through them without exceeding their plate dissipation. A battery operated pentode 1N5GT was used as an amplifier tube, the plate of which was directly connected to the grids of 6L6's.

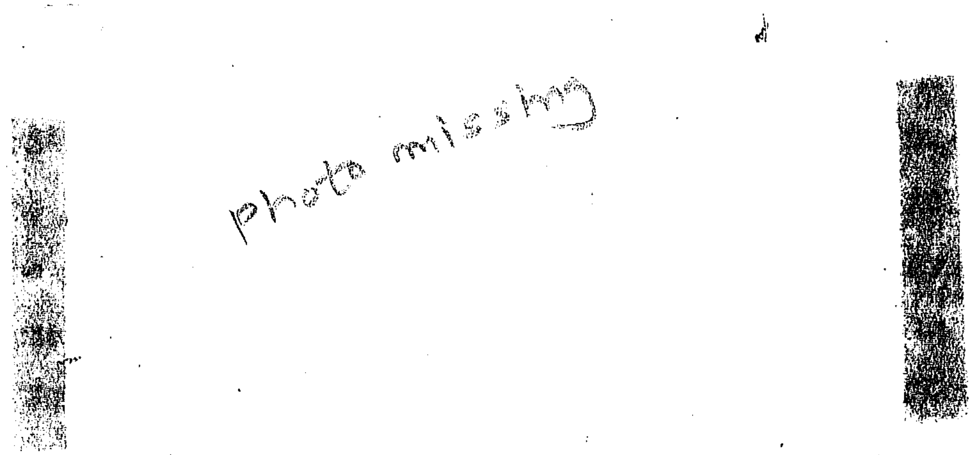

Fig.7. Stabilised D.C. filament power supply for the receiver.

The filament of the 1N21T was heated directly from the stabilised output voltage with a proper voltage dropping resistor in series with it. A battery of dry cells (24 volts) was used as a reference voltage. The performance of this circuit has been satisfactory.

3 - SAMPLE RECORDINGS OF COSMIC RADIO NOISE ON 25 Mc/s AT AHMEDABAD

Fig.9 represents three samples of cosmic radio noise records on 25 Mc/s made at Ahmedabad, by means of an equipment described above, during the IGY and IGC.

Fig.9(a) illustrates the cosmic-noise record on 1 and 2 July 1957. The chart speed has been one inch per hour. The times written on the upper and lower sides of the charts are 75° EMT and sidereal time respectively. The intensity of the cosmic-noise at a given time depends upon which portion of the sky the aerial is looking at and the ionospheric attenuation at that time. The presence of solar noise storm on 1 July 1957 is evident during noon hours from 1030 to 1330 hours. After 1400 hours, the record shows a broadening due to the atmospherics superimposed over the cosmic noise background. It is almost free from disturbance 2230 hours onwards. It is calibrated manually in terms of diode-noise generator current at 0315 hours and 1300 hours. It is clear that the receiver input/output characteristics are not linear. In order to

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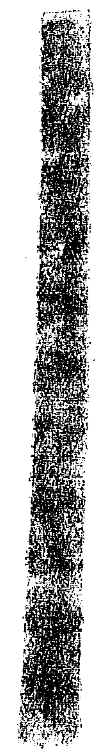

Fig.9(a),(b) and (c). Illustrating sample cosmic-noise recordings made at Ahmedabad.

determine the intensity of cosmic-noise at a particular time, it is first necessary to count the number of divisions on the chart from the zero-level to the base of cosmic-noise level and then using a calibration curve relating chart divisions to the noise-diode current, the intensity of cosmic radio noise can be read on a linear scale. As has been explained earlier, zero-marks indicate the receiver noise level when the antenna is replaced periodically for a short time by a cold resistor of 100 ohms, so that if there be any drift in the instrument it can be corrected for. In this particular record the maximum amplitude occurred at about 1200 hours local time due to the solar radio bursts and at 0030 hours when the galaxy was overhead. The galaxy being a diffuse source of radio noise shows a broad maximum. The cosmic noise recording instrument was automatically paralysed for about 5 minutes every 15 minutes on 1 and 2 July in order to avoid pickup of strong radiation from the nearby pulsed transmitter used for vertical ionospheric soundings. Normally this is done for 5 minutes every hour. In the absence of such an automatic paralysing arrangement, the appearance of the cosmic noise recordings would have been spoilt.

Fig.9(b) shows a similar record but taken on 29 and 30 April 1958. This record shows a disturbance due to atmospherics from 1100 hour onwards on the 29th till about 0100 hour on the 30th April. After this the appearance of the cosmic radio noise was smooth as indicated by the absence of spikes on the record. After sunrise, a weak interference due to atmospherics is evident. It is worthnoting that the maximum due to galactic radiation, which occurred at midnight in the first week of July 1957, has now shifted to 03 hour local time in the last week of April 1958. This observed local time-difference in the occurrence of the maximum in the cosmic radio noise is to be expected, since it depends upon the sidereal time and not on the solar time.

Fig.9(c) shows a cosmic noise record on 27 and 28 September 1959. Due to the sidereal time dependence, the peak of the galactic radio noise has now shifted to evening between 1900 to 2000 hours. But its shape is distorted owing to rapid rise in ionospheric attenuation after 1930 hours. This record also exhibits disturbance due to atmospherics but the cosmic-noise base-level can still be identified. In severe cases, one has to reject such records. This record became free from interference due to atmospherics and also from ionospheric attenuation after 2300 hours local time on 27 September 1959. Another smaller peak in intensity made its appearance between 05 and 06 hours. This second peak did not reveal itself in the last two records, since it was suppressed due to the daytime ionospheric attenuation.

From the above discussion of the cosmic noise records, one can conclude that the intensity of the cosmic-noise as measured on the surface of the earth depends on : (1) its variation with sidereal time and (2) ionospheric transparency which on most days depends on the local time.

CHAPTER IV

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CHAPTER IV

EXPERIMENTAL RESULTS OF MEASUREMENT OF COSMIC NOISE ABSORPTION ON 25 MC/S AT AHMEDABAD

1 - INTRODUCTION

Ionospheric absorption studies using extra-terrestrial radio waves in low latitudes have been few. Continuous recording of the intensity of cosmic-noise on 25 Mc/s was started in March 1957 with a view to studying the ionospheric absorption at Ahmedabad. In this chapter, the results of the observations on ionospheric absorption using cosmic radio noise on 25 Mc/s made at Ahmedabad during the periods March 1957 to December 1959 are described and analysed. This study has revealed many interesting features of the behaviour of the ionosphere over Ahmedabad. On some days, the cosmic-noise recordings were badly disturbed due to station-interference, atmospherics, equipment failure etc., but in most months, useful data for more than 20 days in a month were available.

2 - METHOD OF CALCULATING IONOSPHERIC ATTENUATION USING COSMIC RADIO NOISE

The method of calculating ionospheric attenuation will first be briefly outlined. The directional aerial scans the same strip of the sky once in a sidereal day owing to the diurnal rotation of the earth about its axis and the amount of cosmic noise picked by the aerial depends firstly upon sidereal time and secondly, upon the transparency of the ionosphere, which is a function of local time. It is necessary to know the amount of the incident cosmic noise power, which is assumed to remain constant, outside the earth's atmosphere. This can be known with fair accuracy if one has reliable cosmic noise data for a period of one year. From these data, cosmic-noise intensities for each sidereal hour, under minimum or negligible ionospheric attenuation, are determined. If the critical frequency of the F region is below 3 Mc/s and if it is nighttime after midnight, then the cosmic noise intensities for any sidereal hour are found to be repeated with an accuracy of ± 5 %. Such conditions in the ionosphere, usually occurred between 03 to 05 hours local time. Records were chosen using this criterion and a normal curve of unabsorbed intensity of cosmic radio noise against sidereal time was built up as shown in Fig.1. It is a smooth double humped curve; the first hump occurs at 06 hour sidereal time and another bigger hump at 19 hour sidereal time. There are two minima, one at 0 hour sidereal time and the other, a sharp minimum at 09 hour sidereal time. Now if one compares the observed intensity at any hour with that given by the "Standard Curve" at the same sidereal time, then one can calculate the ionospheric attenuation by the formula

$$\text{Attenuation (decibels)} = 10 \log_{10} \frac{P_s}{P_o}$$

where P_s = Cosmic noise power extrapolated for a position outside the earth's atmosphere at any time

and P_o = Cosmic noise power as measured on the surface of the earth at the same sidereal time.

For example, in terms of noise-diode d.c. current, which is proportional to the noise power, if

$P_s \propto 30$ and $P_o \propto 15$, then Attenuation in db =

$$10 \log_{10} \frac{30}{15} = 10 \log_{10} 2 = 10\ (0.301) = 3.01.$$

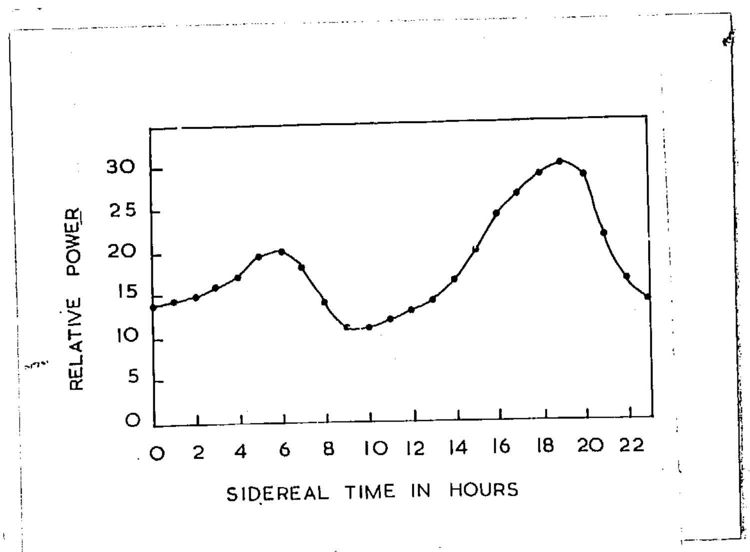

Fig.1. Unabsorbed intensity of cosmic radio noise on 25 Mc/s against sidereal time with the antenna used at Ahmedabad.

3 - TOTAL IONOSPHERIC ATTENUATION OF COSMIC-NOISE ON 25 MC/S AT AHMEDABAD

Using this simple method, the total ionospheric attenuation at each hour on all possible days in different months was computed during the period March 1957 to December 1959. In Fig.2 are plotted the monthly mean hourly values in decibels of the total ionospheric attenuation in the whole of the ionosphere including the region beyond the level of maximum ionization of the F_2-region.

A paper[13] containing an analysis of the cosmic-noise data from March 1957 to February 1958 has been published. A reprint of it is appended. This preliminary study showed that a minimum of total attenuation invariably occurred between midnight and sunrise. This was true for all seasons. The daytime maximum in the total attenuation was reached by about 1400 hour local time, the maximum value being slightly different for different months as set out in table I. Thereafter the total attenuation decreased till about 1900 hr. The daytime peak occurred in the forenoon at about 1100 hr in December 1957 but this was an exceptional month. After sunset, the total attenuation displayed two distinct types of variation, in one case it continued to decrease throughout the night and in another, it showed a temporary rise to a maximum somewhere between 20-21 hr local time followed by a steady decrease in the rest of the night.

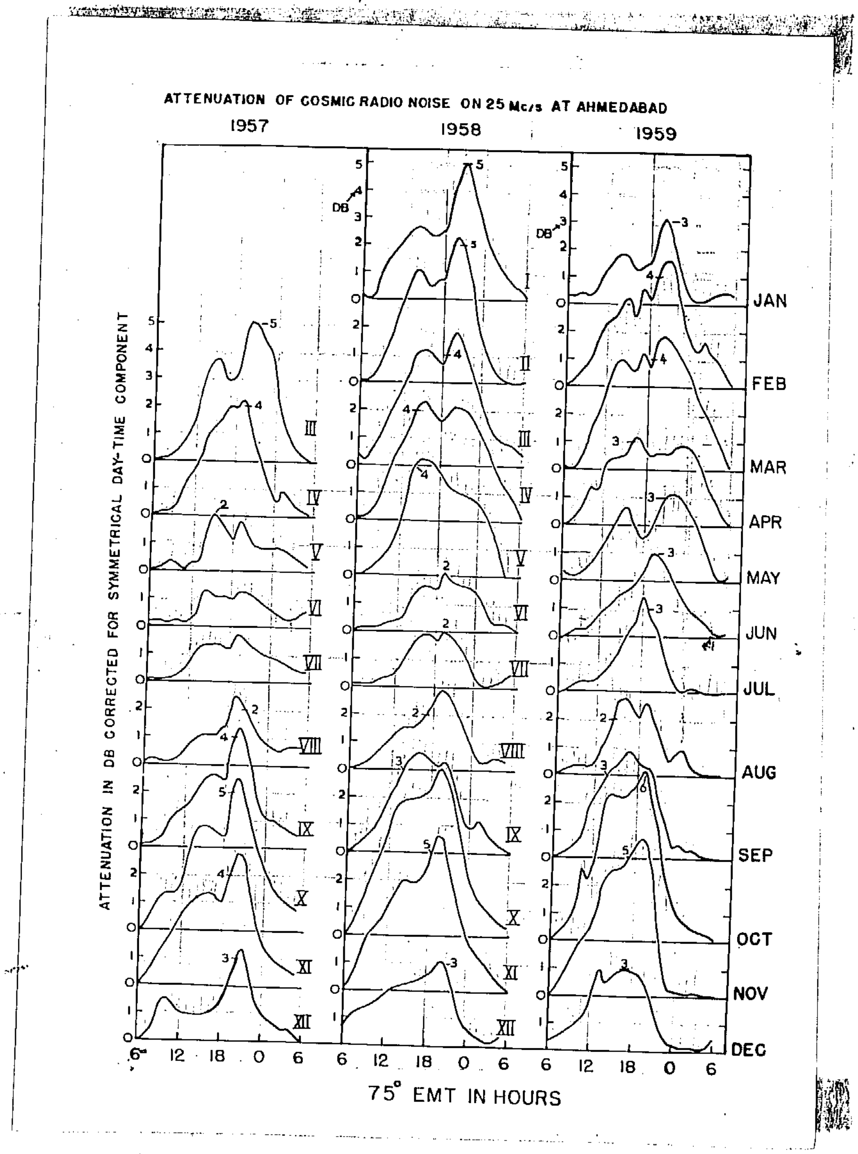

Fig.2. Monthly mean hourly values in db. of the total ionospheric attenuation of cosmic radio noise on 25 Mc/s at Ahmedabad from March 1957 to December 1959.

Table I

Mean time of occurrence in hr 75° EMT of maximum daytime total attenuation and its value in db.

Month / Year	J	F	M	A	M	J	J	A	S	O	N	D
1957	No observation		14/5.6	16/4.9	15/4.0	14/3.4	13/3.1	13/3.3	15/5.0	14/6.5	14/4.6	11/2.4
1958	13/4.1	14/5.3	14/5.3	14/5.8	14/4.5	15/3.2	16/2.9	14/5.0	15/4.3	13/6.9	14/6.4	12/5.1
1959	14/2.5	14/3.3	14/5.0	16/3.7	15/3.1	14/2.8	13/3.5	13/3.7	14/5.4	14/7.3	14/6.1	15/3.7

Table II

Mean time of occurrence in hr 75° EMT of maximum nighttime total attenuation and its value in db.

Month / Year	J	F	M	A	M	J	J	A	S	O	N	D
1957	No observation		21/5.1	-	-	-	-	-	20/4.3	20/5.5	20/4.8	21/3.3
1958	21/5.0	20/5.3	20/4.8	21/4.1	-	-	-	19/3.0	20/3.3	19/6.0	19/5.3	20/3.2
1959	20/3.2	21/4.6	20/4.8	23/2.9	22/3.1	20/2.9	-	19/2.6	-	19/6.3	19/6.3	-

Tabulated numbers signify $\frac{\text{hour}}{\text{db}}$

Gap in Table II means a steady fall during the night without a maximum.

The pre-midnight peak in the total attenuation was pronounced during winter and equinoctial months while no such peculiarity was observed in summer. The occurrence of this pre-midnight peak was thought to be in someway connected with F-scatter. In a recent communication Ramanathan and Bhonsle[16] have drawn attention to the new evidence that the additional nighttime peak is related to F-scatter from the work of Bateman and others[44] who have discussed the observations of F-scatter during the IGY in the Philippines-Okinawa area. They observed anomalous enhancements, during evening hours of the signals transmitted at VHF between the Philippines and Okinawa. The enhancements were found to occur with greatest frequency in September and October. They usually lasted several hours beginning at about 19 hr at the midpoint of the transmission path. The signal intensity usually increased rapidly, then levelled off, and finally dropped back below the normal scatter level around midnight. Bateman and his co-workers have examined the ionospheric data from Baguio, Philippine Islands and Okinawa ionospheric stations during September 1957, a period of anomalous propagation. No association between the anomaly and E-region effects could be detected, but the periods of anomalous propagation did correspond to those of spread-F at Baguio and high critical frequencies at Okinawa. They suggested that the enhanced signal was propagated via the F-region and was enhanced when there was spread-F in that region. Spread-F echoes show a maximum in the equinoxes of high sunspot years and a negative correlation with magnetic activity at Ahmedabad (Kotadia and Ramanathan).[61]

4 - TOTAL IONOSPHERIC ATTENUATION IN 1958 AND 1959

In 1958, the minimum total attenuation occurred between midnight and sunrise in all the months in agreement with the results of the previous year. Table I gives the mean time of occurrence in hours 75° EMT of the maximum daytime total attenuation and its value in db for the different months in 1958. It will be seen that the maximum daytime peak in attenuation occurred in the afternoon in all the months in 1958 except for minor shifts in the times of occurrence. The nature of diurnal variation was not changed significantly from 1957 to 1958. The only noticeable change was the development of a new pre-midnight peak in the months of April and August 1958. After sunset, the rate of decrease of the total attenuation in summer was smaller in 1958. The pre-midnight peaks in attenuation in October, November and December 1958 were not as prominent as in 1957.

An examination of the diurnal curves of total attenuation in 1959 reveals significant departures from the trends in the previous two years. Except in July 1959, the maximum daytime attenuation occurred between 14 and 15 hr.

In July 1959, it occurred at 1300 hour. In January and February 1959, the overall attenuation decreased considerably, though they showed the two usual maxima. The months of March and April 1959 showed progressively smaller values of daytime attenuation but the nighttime attenuation remained appreciably large till about 4 hr in the morning. In April 1959, there developed a very broad peak at 2300 hr. The month of May 1959 proved to be exceptional, since after the usual daytime peak at 14 hr, the attenuation decreased till 16 hr, but again increased to a high value at about 22 hr. This was not expected to happen from the previous years' data. In June 1959, a broad nighttime peak developed at about 20 hr which was absent in the same month in 1957 and 1958. The total daytime attenuations in August, September and October and December 1959 were consistently higher than the corresponding values in the previous years. The nighttime maximum in attenuation became progressively smaller and completely disappeared in September and December 1959. In November and December 1959, it dropped to its minimum value well before midnight.

5 - MEAN MONTHLY VARIATION OF THE TOTAL IONOSPHERIC ATTENUATION IN 1957, 1958 AND 1959

From the discussion in the last section, it is evident that the amount of total attenuation of cosmic noise undergoes a marked variation both diurnally and seasonally.

In this section, it is proposed to discuss its seasonal variations in 1957, 1958 and 1959. This is done by comparing the mean values of the total attenuation for different months. The monthly mean values of the total attenuation were calculated by averaging the 24 mean hourly values for each month. In Fig.3 are plotted the monthly mean values from March 1957 to December 1959. It will be seen that the monthly mean values of the total attenuation show maxima in the equinoctial months and minima in summer and winter. This is true for all the three years. The maximum occurring in October in each year was stronger than the one occurring in March. The monthly mean total attenuation reached its highest maximum, 3.8 db, in October 1958.

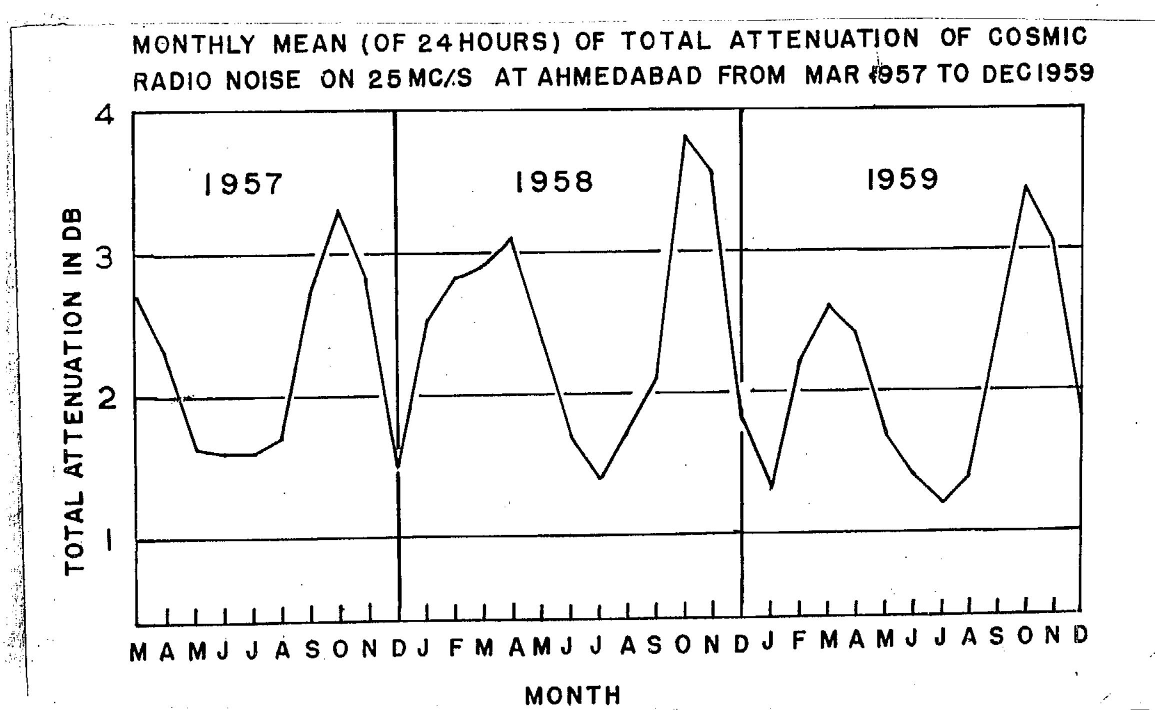

Fig.3. Monthly mean values (mean of 24 hours) of the total attenuation of cosmic radio noise at Ahmedabad for the period from March 1957 to December 1959.

In 1957, the monthly mean total attenuation remained at a low value during the whole summer extending from May to August. As against this, in 1958 and 1959 well-defined sharp minima occurred in the month of July. A sharp minimum was also recorded in December 1957 but the next winter-minimum was delayed by a month; it occurred in January 1959.

6 - DEPENDENCE OF THE TOTAL ATTENUATION OF COSMIC RADIO NOISE OF 25 MC/S ON THE CRITICAL FREQUENCY OF THE F_2-REGION

Evidence that a part of absorption of cosmic noise is to be ascribed to the F-region was obtained by Mitra and Shain[9] who found a correlation between the total absorption of cosmic radio waves on 18.3 Mc/s and f_oF_2 values above 5 Mc/s. Analysis of a similar character by Blum, Denisse and Steinberg[10] revealed a partial absorption attributable at 30 Mc/s to F-region. According to them, the absorption varies with f_oF_2 almost linearly while according to Mitra and Shain, a curvilinear relation holds good over the range 4 to 8 Mc/s. At times when diffuse or spread F layer echo conditions prevail, there is much less clear relationship with f_oF_2 values. Analysis by Bhonsle and Ramanathan[15] (reprint appended) of the cosmic radio noise absorption on 25 Mc/s from March 1957 to February 1959 at Ahmedabad showed that, in general, when f_oF_2 exceeded 8 Mc/s the attenuation increased rapidly with increasing f_oF_2. Fig.4 shows a scatter plot of the total attenuation observed during 1958 and 1959 against f_oF_2. Since a large amount of data over an extended period was available, we have plotted the monthly mean hourly attenuations and the corresponding monthly median hourly values of f_oF_2 to establish a relationship between them.

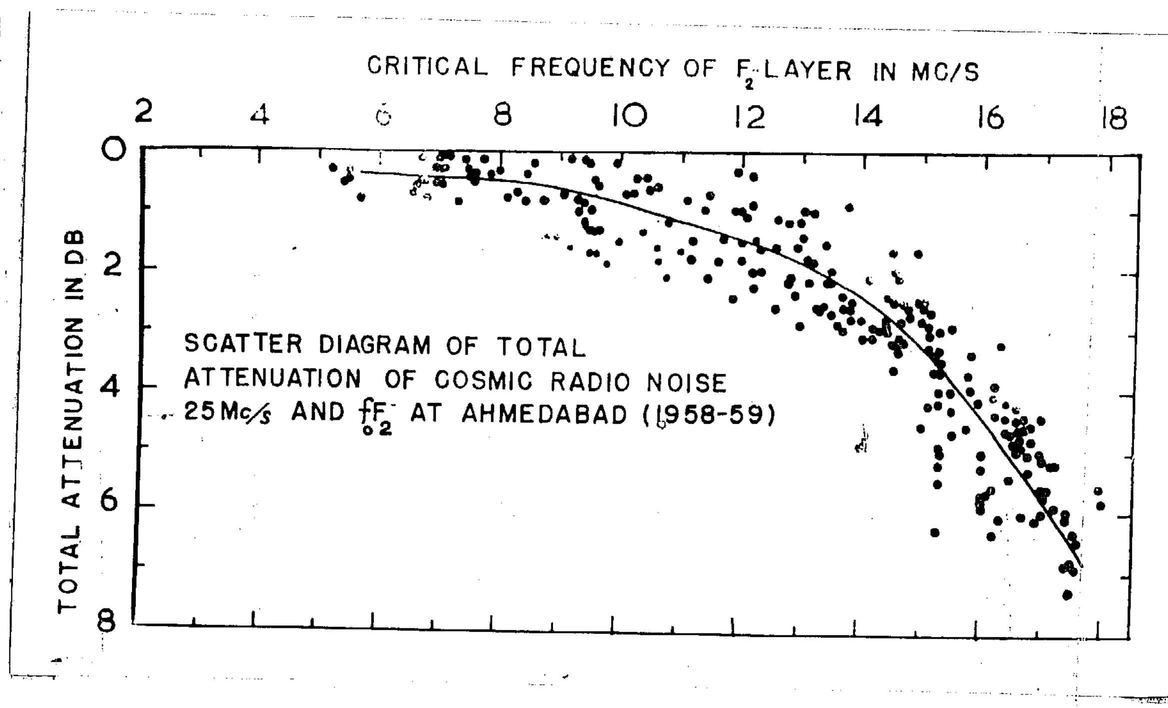

Fig.4. Scatter plot of the total attenuation against f_oF_2 during 1958 and 1959.

Fig.5. $\log_{10}$ A against $\log_{10}$ (f_oF_2).

Fig.5 shows the plot of $\log_{10} A$ against $\log_{10} f_oF_2$. The majority of the points lie on a straight line whose equation is given by

$$\log_{10} A = \bar{1}.7 + K (\log_{10} f_oF_2 - \log_{10} f_o) \qquad ...(1)$$

where A is the total attenuation in db,

K is the slope of the line with a value 3.4,

f_oF_2 = critical frequency of the F_2 region in Mc/s

and $f_o \approx 8$ Mc/s.

The equation (1) may also be written simply as

$$A = \frac{1}{2} (f_oF_2/f_o)^{3.4} \qquad ...(2)$$

7 - SEPARATION OF A DAYTIME COMPONENT SYMMETRICAL ABOUT NOON FROM THE TOTAL ATTENUATION

The total ionospheric attenuation is caused by the individual contributions of the different ionospheric regions including the region beyond the maximum of F_2. It is expected both on theoretical grounds and from empirical data, that an important fraction of the total attenuation would be a daytime effect depending on the solar zenith angle with maximum near noon and smaller values in the morning and evening. Mitra and Shain[9] devised a method to separate the F_2-region component of absorption from the total attenuation. To do this, they plotted the total attenuation against f_oF_2 for each solar hour, and extrapolated the curve for low values of f_oF_2. There was still a residual absorption, and the extrapolated residual absorption showed solar control with maximum value near noon and minimum values in the morning and evening hours. They found the residual absorption to obey a $\cos^n \chi$ relation and attributed it to the D-region of the ionosphere.

The same method was applied to the Ahmedabad data by Bhonsle and Ramanathan[15]. Analysing the cosmic noise absorption data for the period March 1957 to February 1958, it was shown that below 8 Mc/s, the total attenuation showed little variation with f_oF_2 and could be considered independent of f_oF_2. In Fig.6, the total attenuation is plotted against f_oF_2 for three different solar hours in August 1957 (6 hr, 9 hr and 12 hr).

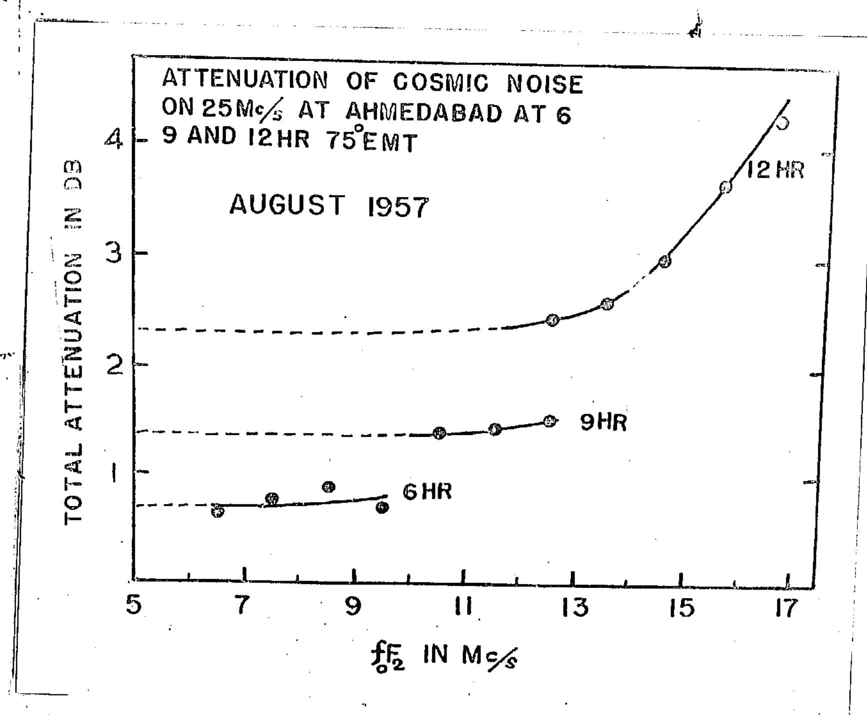

Fig.6. Total attenuation against f_oF_2 for different solar hours in August 1957. The total attenuations are averaged over 1 Mc/s interval of f_oF_2.

Extrapolation to zero F_2-attenuation involves no difficulty in the morning hours when f_oF_2 values are small. It becomes less accurate in the afternoons when f_oF_2 values are large. The residual absorptions, which are symmetrical around noon at Ahmedabad are plotted in Fig.7 for the period March 1957 to December 1959. They show reasonably good symmetry around local noon in all the months. There is however some delay in the occurrence of the maximum of the D-region absorption beyond noon. Analysis of the cosmic noise data at Ahmedabad showed an average lag of 28 min beyond noon, which is in good agreement with Mitra and Shain's value of 27 min. The morning values of the residual absorption were on the average more reliable than the afternoon ones. In some months particularly in 1958 and 1959, precise values of f_oF_2 in the afternoons were not available owing to equipment trouble. Such curves are shown dotted in the diagram. It is clear that the diurnal variation of the daytime symmetrical component of absorption obeys a relation of the type $(\cos\chi)^n$. In 1957, the values of the exponent 'n' were determined for each month. Averaging over different months, it was found that during summer and equinox 'n' was 1.1 and 1 respectively while during winter it was 0.8. The corresponding values of 'n' in 1950 found by Mitra and Shain[9] were 1.1 in summer, 0.9 in equinox and 0.5 in winter.

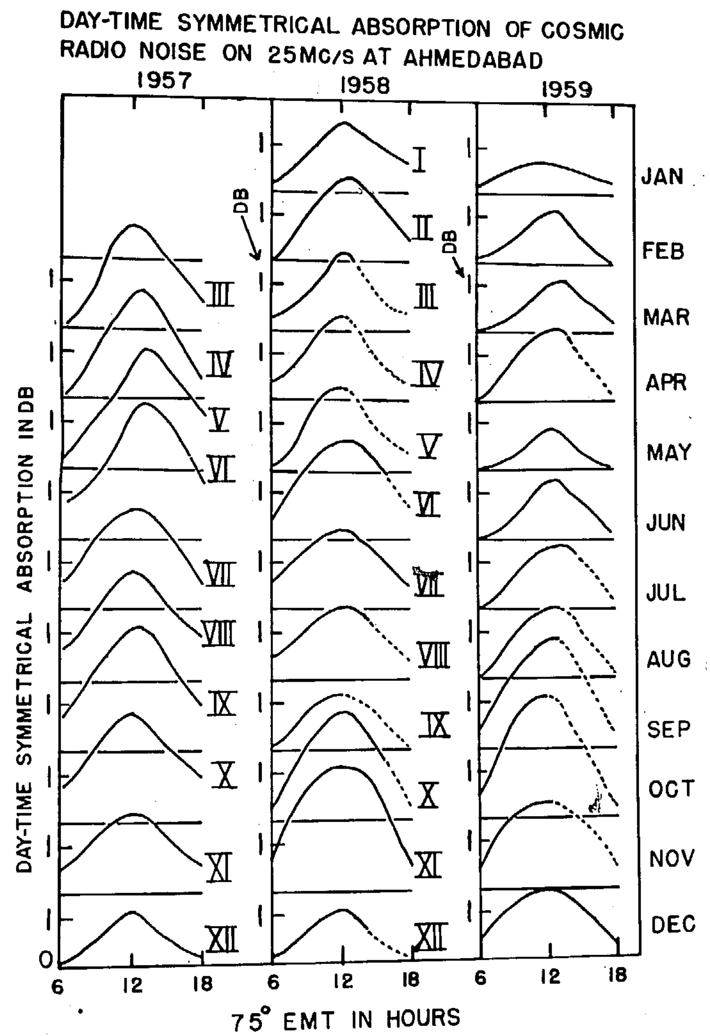

Fig.7. Daytime component of absorption symmetrical around noon for the period March 1957 to December 1959.

3 - SEASONAL VARIATION OF NOON ABSORPTION CORRECTED FOR F-ATTENUATION FROM MARCH 1957 TO DECEMBER 1959

The noon value of the daytime $\cos^n \chi$ absorption was obtained for each month by extrapolating the total attenuation for zero f_oF_2. These monthly values are plotted for the period March 1957 to December 1959 in Fig.3.

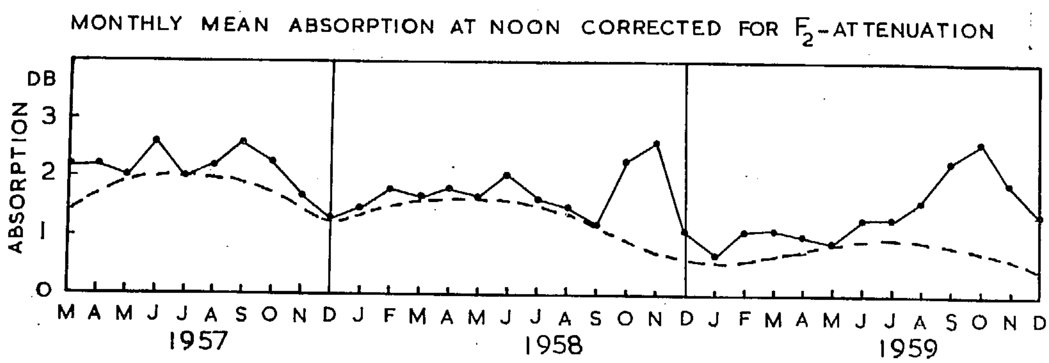

Fig.3. Monthly mean noon-absorption corrected for F-attenuation from March 1957 to December 1959.

Although there is a progressive decrease in the noon values of summer and winter from year to year, the seasonal variation is not regular. In autumn, there occurred pronounced maxima in the noon-$\cos^n\chi$ absorption in all the three years. In 1959, the development of the peak began as early as August and reached a maximum in October. The expected seasonal variation of noon-$\cos^n\chi$ absorption should have shown maximum amplitude in summer and minimum in winter as shown by the dotted line in Fig.3, with intermediate values in equinoxes. It is significant that the phenomenon has been repeating itself since 1957 from year to year. It is suggested that, although the so-called D component of absorption shows symmetry around the local noon, its source may not be entirely in the D region but there may be a contribution from the higher regions of the ionosphere.

C - F-REGION ATTENUATION OF COSMIC RADIO NOISE ON 25 MC/s AT AHMEDABAD

It has been found convenient to divide the total attenuation into two components :

i) A symmetrical component whose diurnal variation obeys $(\cos\chi)^n$ law, and

ii) A residual non-symmetrical component which does not obey $(\cos\chi)^n$ law.

The symmetrical component of absorption is supposed to originate in those ionospheric regions which are under direct solar control, with very little time-lag between change in solar radiation and its effects. The method of separating this from the total attenuation has already been described. The D, E and F_1 regions can all contribute to the symmetrical component. As these layers disappear soon after sunset and only the F_2 layer persists throughout the night, we have to examine the behaviour of the F_2 layer. f_oF_2 exhibits characteristic diurnal and seasonal variations and Ahmedabad is situated in a belt of magnetic latitude at which the critical frequencies of the F_2-layer reach their peak. Hence it was expected that large attenuation of extra-terrestrial radio noise would occur in passing through the ionosphere over Ahmedabad. The F_2 critical frequencies observed at Ahmedabad reach their maximum value by about 14 hr. In winter and equinoctial months, another increase in f_oF_2 occurs which lasts till 21-22 hours. The F_2 layer is sensitive to tidal forces, and geomagnetic storms. During magnetic storms, the critical frequencies of the F_2 layer get much depressed and large increases in h_pF_2 take place. During nighttime, the occurrence of F-scatter is common and this is likely to give rise to additional attenuation.

If we subtract the symmetrical $\cos^{n}\chi$ component from the total attenuation then whatever remains may be called asymmetrical component of attenuation whose major portion may occur in the F region and in the region beyond the maximum of F_2. Fig.9 shows the monthly mean hourly values in decibels of the asymmetrical component of attenuation. The difference between these curves and the curves of total attenuation is only in the day-hours from 6 hr to 18 hr. Afterwards, they are identical. The asymmetrical component of attenuation goes on increasing with increase in f_oF_2, if it exceeds about 8 Mc/s. It can be seen from Fig.9 that usually the asymmetrical component reaches its daytime maximum value in the afternoon. In December 1957, it reached its maximum value in the forenoon at about 11 hr but this was the only instance of such exceptional variation.

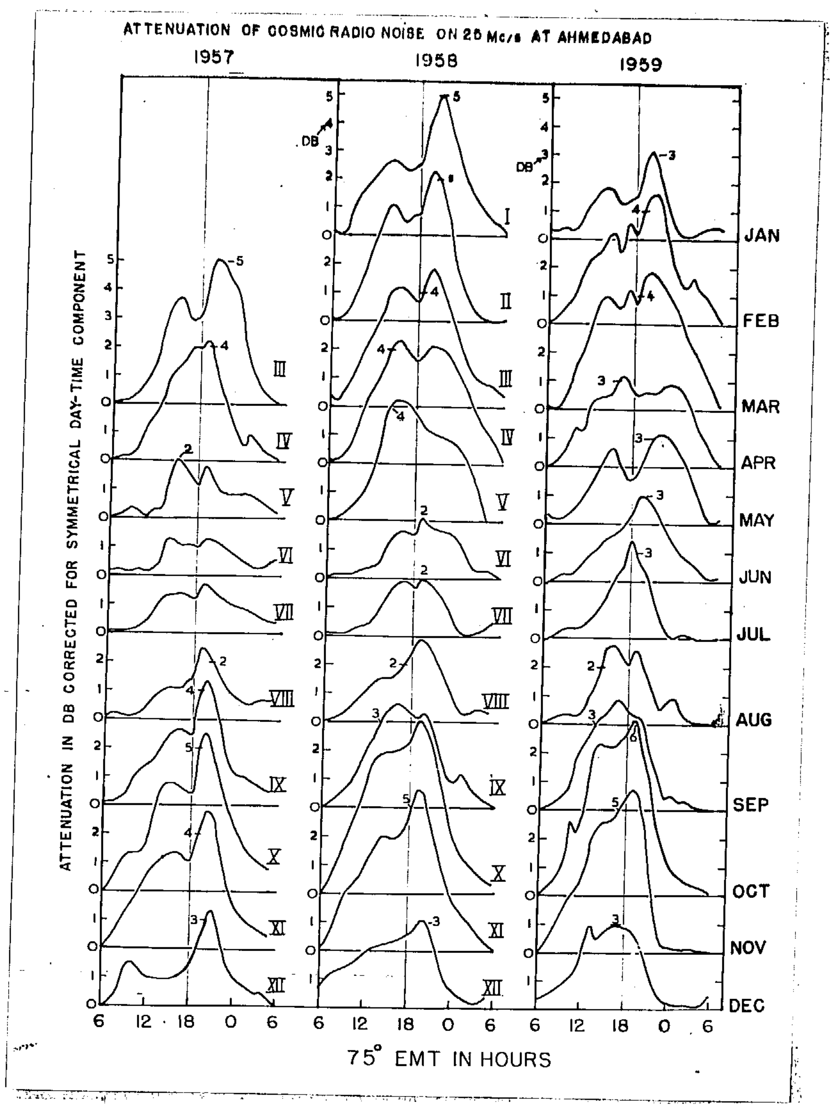

Fig.9. Monthly mean hourly values in db of the asymmetrical component of absorption of cosmic radio noise on 25 Mc/s at Ahmedabad from March 1957 to December 1959.

10 - F-REGION COMPONENT OF ATTENUATION AND ITS VARIATION WITH THE CRITICAL FREQUENCY OF THE F_2-LAYER

Having determined the monthly mean hourly values of the asymmetrical component of attenuation for the period from March 1957 to December 1959, a comparative study of its variations with changes in f_oF_2 was made. This was done for different seasons by combining the hourly attenuations March and April, June and July, October and November and December for 1957, 1958 and 1959. The f_oF_2 data were also combined in a similar way.

Fig.10 shows the monthly mean hourly values in db of the asymmetrical component for the above periods. The corresponding median values of f_oF_2 are also plotted in each case and these are shown by the dotted lines. In some months in 1958 and 1959, the median f_oF_2 values were not known with accuracy. Such points are shown by arrows. In June-July of each year, the f_oF_2 values were not high, therefore, we do not find large asymmetrical attenuations, whereas in October-November and December, large f_oF_2 values occur with consequent rise in the attenuation. The early night values of f_oF_2 in summer are lower than the corresponding values in equinoxes and winter. During these periods, the attenuations showed large values. It will be noticed that in winter and equinoctial months in 1957 and 1958, the attenuation starts increasing

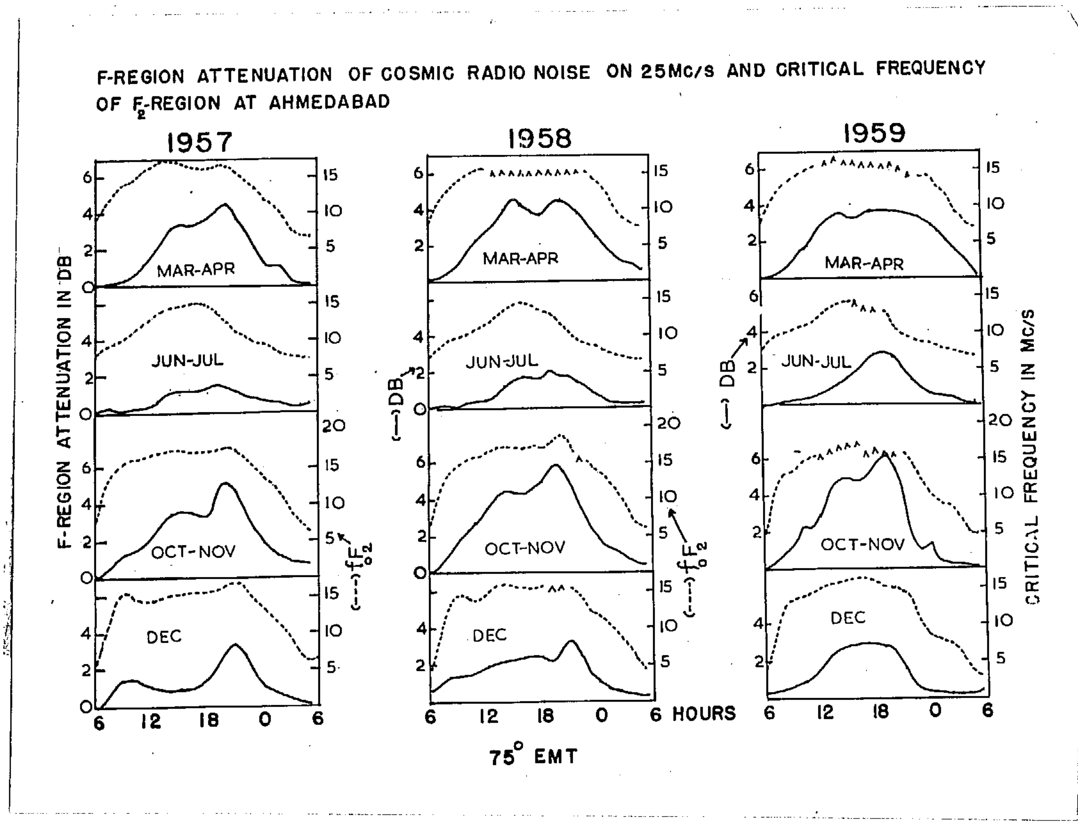

Fig.10. Monthly mean hourly values in db of the asymmetrical component of attenuation of cosmic radio noise on 25 Mc/s and the corresponding median values of f_oF_2.

sharply after 1900 hr. It reaches a maximum somewhere between 20-21 hr and then decreases during the rest of the night. No such increase in attenuation after sunset is noticed in summer. It is also evident from Fig.10 that attenuations observed in the morning and evening for the same value of f_oF_2 are not the same. This suggests that, there is some additional factor which causes an extra-attenuation in the evening. The difference in the variation of attenuation with f_oF_2 in the pre- and post-midday hours, can be seen from Fig.11, in which plots are made of attenuation against f_oF_2 for March-April, June-July, October-November and December in 1957, 1958 and 1959. The difference between daytime and nighttime attenuations for the same critical frequency is maximum in March-April for all the three years. This difference goes on decreasing progressively towards winter. In December, in all these years, it is the least. This shows that, the disparity in day and night attenuations for the same f_oF_2 exhibits seasonal variation. This observed fact can be studied on an yearly basis by comparing mid-day attenuations with nighttime attenuation (say) at 20 hr for all the months. The nighttime observation at

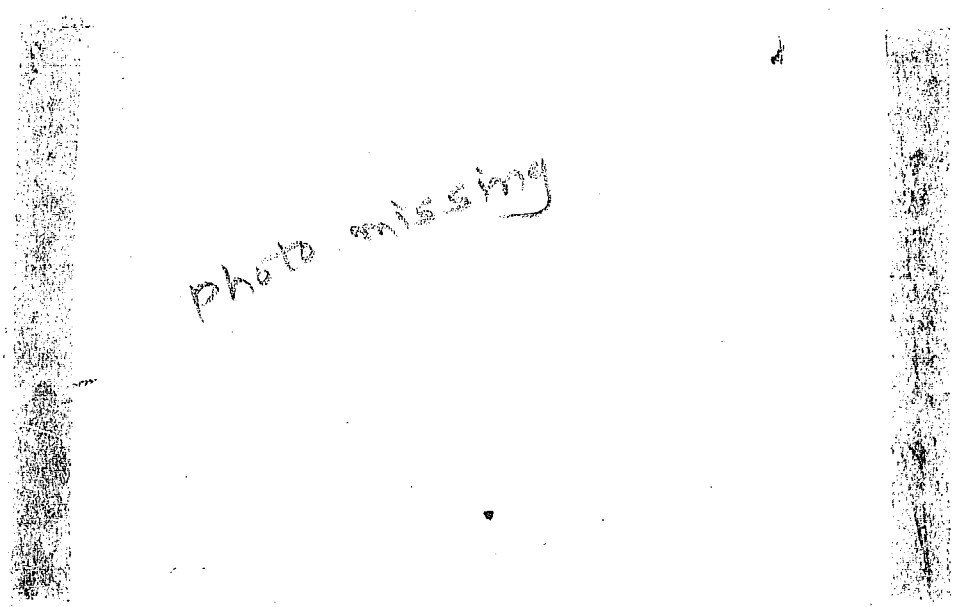

Fig.11. Plots of pre- and post-midday attenuations against f_oF_2.

20 hr has been deliberately chosen for comparison with 12 hr, because in winter and equinoxes between 20-21 hr a nighttime peak in attenuation is observed. In Fig.12 are plotted monthly mean asymmetrical components of absorption at 12 and 20 hr along with the corresponding values of f_oF_2. It will be noticed that attenuation, both at 12 hr and 20 hr, follow the respective changes in f_oF_2, but the correlation seems to be better for the day values. It may also be noted that, in general, 20 hr attenuations were always higher than the 12 hr attenuation for the same f_oF_2. One can get some idea of the average difference between the daytime and nighttime attenuations from Fig.13, where 20 hr and 12 hr attenuations are plotted with different symbols against f_oF_2.

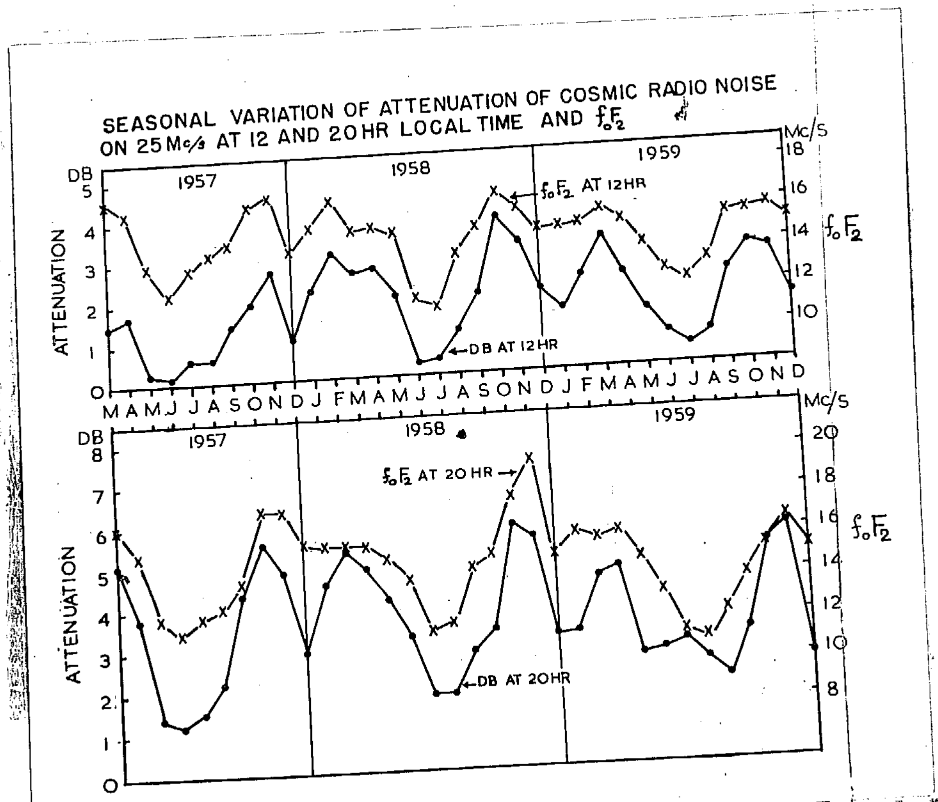

Fig.12. ... absorption at 12 and 20 hr and corresponding values of f_oF_2.

It will be seen that the excess of 20 hr attenuation over the 12 hr attenuation for the same f_oF_2 is of the order of 1.5 to 2.0 db. This additional attenuation at 20 hr may be partly due to the scattering of radio waves due to irregularities in the electron distribution in the ionosphere. The point is receiving further attention in the Laboratory.

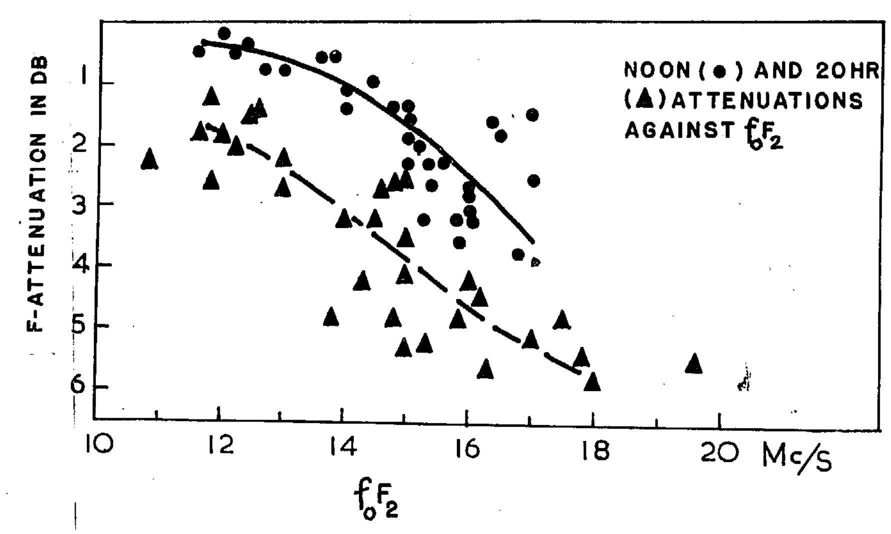

Fig.13. Scatter plot of 12 and 20 hr attenuations against f_oF_2 showing excess of nighttime attenuation over day time attenuation for the same f_oF_2.

11 - COMPARISON OF THE TOTAL NOON ATTENUATIONS OF COSMIC RADIO NOISE ON 25 MC/S AT AHMEDABAD WITH SIMILAR OBSERVATIONS AT OTHER STATIONS

Having seen that the total ionospheric attenuation of cosmic radio noise on 25 Mc/s at Ahmedabad changes significantly with the time of day and with season, let us compare the noon-values of total attenuation in different seasons at Ahmedabad with similar observations made at other places. Table III gives a summary of the observations at various stations in different latitudes. The observations are not directly comparable since they are made at different phases of the solar cycle and also at different frequencies. It is however possible to get some idea of the orders of magnitude Mitra and Shain[9] analysed the cosmic radio noise data on 18.3 Mc/s relating to selected periods in different seasons in 1950. They found that the maximum attenuation occurred in summer and the attenuations were somewhat less in both winter and equinoxes.

Cosmic noise observations of Blum, Denisse and Steinberg on 29.5 Mc/s made in France in 1949 showed comparatively smaller attenuation. This is understandable. They worked at a higher latitude and also at a higher frequency. The symmetrical component of absorption decreases with increasing zenith distance of the sun and also with $1/\omega^2$.

Table III

Comparison of the total noon-attenuations of cosmic radio noise on 25 Mc/s at Ahmedabad with similar observations made at other stations.

Place	Lat.	Long.	Year	Authors	Freq.in Mc/s.	Total noon-attenuation in db Summer	Equinox	Winter
Hornsby	34°S	151°E	1950 (6 months)	Mitra and Shain	18.3	1.3	0.85	0.9
Marcoussis	40°N	2°E	1949	Blum, Denisse and Steinberg	29.5	0.5		
Ahmedabad	23°02'N	72°38'E	1957	Bhonsle and Ramanathan	25.0	2.3	4.0	3.8
"	"	"	1958	Bhonsle	"	2.7	4.5	3.6
"	"	"	1959	Bhonsle	"	2.1	4.4	3.3
Hawaii	21°N	157°W	1958 (3 weeks)	Fredriksen and Dyce	27.6	0.75		
Johnston Island	16°45'N	169°, 31'W	Do	"	"	0.4		
Bikini	12°N	165°E	Do	"	"		1.25	

Our measurements of cosmic noise attenuation on 25 Mc/s at Ahmedabad, in the period of high solar activity (1957) showed that the values of total attenuation were many times larger than those observed by Mitra and Shain. The total attenuation was maximum in the equinoxes and minimum in summer. The total attenuation in winter was slightly less than its equinoctial value. Bhonsle extended the analysis of the noon total attenuation for a further period of two years from 1958 to 1959. Attenuation in summer showed a progressive decline from 1957 to 1959, but the attenuation in equinoxes increased in 1958 and maintained at almost the same value in 1959. The winter-attenuation, however, has not changed appreciably in the course of the three years.

Fredriksen and Dyce[45] worked with riometers for a short period at 27.6 Mc/s at Johnston Island, Hawaii and Bikini. The total attenuations at these stations were much smaller than those at Ahmedabad eventhough the observations were made on nearly the same frequency.

Ahmedabad's situation on the belt of magnetic latitude where the highest frequencies of the F2-region occur, is probably responsible for the high attenuation which has been consistently observed from 1957 onwards.

12

12 - CONCLUSION

From the foregoing discussion, the following conclusions are arrived at :

1) The total attenuation of cosmic radio noise on 25 Mc/s at Ahmedabad can be divided into two components (a) A daytime symmetrical component depending on the zenith distance of the sun, and (b) An asymmetrical component, which does not obey $\cos^n \chi$ law.

2) The total attenuation becomes minimum usually between midnight and sun rise in all the seasons.

3) The total daytime attenuation attains a maximum in the afternoon usually between 14 and 15 hr local time. This is also the time when f_oF_2 has its maximum daytime value.

4) A second maximum occurs in the total attenuation between 20 and 21 hours in certain months. It is suggested that in addition to f_oF_2, F-scatter may contribute to attenuation at these hours.

5) The total attenuation depends on f_oF_2; beyond about 8 Mc/s, the total attenuation increases rapidly with increasing frequency and is empirically given by

$A = \frac{1}{2} (f_oF_2/f_o)^{3.4}$ where A is in db,

f_oF_2 is in Mc/s and

$f_o \approx 8$ Mc/s.

6) The method of separating the symmetrical and asymmetrical components of absorption is described.

7) Seasonal variation of monthly mean total attenuation shows minimum in summer and winter months and maximum in equinoctial months; the maximum which occurs in the October-November is usually greater than that in the March-April.

8) The symmetrical component reaches its maximum slightly after the local noon; the mean delay being of the order of 23 min.

9) The value of the exponent 'n' was found to be 1.1 in summer, 1.0 in equinoxes and 0.8 in winter.

10) The seasonal variation of non-symmetrical absorption shows maximum in equinoxes and minimum in winter and it has intermediate value in summer. This requires further investigation.

11) The F_2-region shows special features in its diurnal and seasonal variation and is sensitive to changes in the earth's magnetic field; similar variations are reflected in the asymmetrical component of attenuation.

12) The pre-midday and post-midday attenuations for the same f_oF_2 are different. For the same f_oF_2 the post-midday values of attenuation are generally higher than the pre-midday values.

13) The seasonal asymmetrical component exhibits two minima similar to f_oF_2, one in summer and another in winter; the winter minimum being the stronger of the two.

14) Comparative study of the attenuations observed at noon at Ahmedabad and at other places shows that the attenuations observed at Ahmedabad have been consistently higher in magnitude from 1957 onwards than those at other places. This is probably due to the situation of Ahmedabad on the belt of magnetic latitude where highest critical frequencies of the F_2-region occur.

13. REPRINTS

i) STUDIES OF COSMIC RADIO NOISE ON 25 MC/S AT AHMEDABAD BY BHONSLE, R.V. AND RAMANATHAN, K.R.

ii) COSMIC RADIO NOISE ABSORPTION ON 25 MC/S AND F-SCATTER BY RAMANATHAN, K.R. AND BHONSLE, R.V.

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Studies of Cosmic Radio Noise on 25 Mc/s. at Ahmedabad

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ATTENUATION of radio waves in the ionosphere is usually measured by comparing the amplitudes of repeated reflections of pulses transmitted upwards from the ground. This method is applicable only for frequencies lower than the critical frequency of the F_2 region at vertical incidence. For frequencies higher than f_0F_2, one would require a transmitter situated outside the earth's atmosphere. Extra-terrestrial radio noise sources in the galaxy provide convenient transmitters for the study of variations in the absorption and scattering of radio waves in the ionosphere.

Jansky[1] was the first to recognize that variations in the ionosphere affect the reception of cosmic radio noise. He attributed the reduction in the intensity of cosmic noise observed during the day to the ionosphere. Systematic observations were taken by Shain[2] using 18.3 Mc/s. in Australia. He concluded that useful information concerning the attenuation of cosmic noise passing through the whole of the ionosphere could be obtained by this means. He found that, so far as absorption was concerned, the F region was more effective than the E region. Mitra and Shain[3] undertook an analysis of the data in greater detail and proved that the total absorption could be divided into two components, one which occurs in the D region and the other in the F_2 region. They calculated the diurnal and seasonal variations and observed that F_2 region absorption was a function of its critical frequency and not its height and suggested that increased night-time absorption might be caused by the irregularities in the F region. Similar analysis carried out by Blum, Denisse and Steinberg[4] revealed a partial absorption attributable at 29.5 Mc/s. to the F region or beyond. Little's[5] work on 65 and 30 Mc/s., which is in progress at College, Alaska, is mainly concerned with high latitude effects such as sudden and intense absorptions associated with the occurrence of visible aurorae and polar blackouts. Warwick and Zirin[6] have analysed the diurnal variation of cosmic noise at 18 Mc/s. in Colorado. Their absorption data did not allow them to separate D region absorption from the absorption produced by the other layers of the ionosphere. They consider that the absorption produced by the other layers is negligibly small. They have derived the electron density as a function of height in the D region and of local time and have inferred that the recombination coefficient, within the D region, is either constant or inceases with height.

The results of experimental work on the ionospheric attenuation using extra-terrestrial noise have so far been mainly reported from stations located in middle and high latitudes. Since 1956, continuous recording of cosmic radio noise at 25 Mc/s. has been going on in the Physical Research Laboratory, Ahmedabad (India) (23°02'N : 72°38'E). This paper presents some of the results of the analysis of the records taken over a period of one year, from March 1957 to February 1958, with a brief description of the equipment and the method of analysis.

Equipment

The equipment consisted of a directional aerial, a suitably modified communications type receiver, a differential type d. c. amplifier, a recording milliammeter and a noise generator. The aerial was a broadside-collinear array consisting of sixteen halfwave dipoles spread in E-W direction and backed by a parallel wire reflector at a distance of 0.2 wavelength. The principal lobe of the aerial had an angular width of about 40° in N-S and 30° in E-W directions, and was directed towards the zenith. The constancy of gain of the receiver and d.c. amplifier necessitated stabilization of their high tension and filament voltage supplies. The output of the receiver was taken from the second detector stage and fed to a stable d.c. amplifier whose output was given to a 0-1 ma. recording milliammeter. The audio-section of the receiver was used to monitor occasional disturbances, due to neighbouring channels, solar bursts and sferics. The receiver output was calibrated manually twice a day, against the noise output of a pure tungsten filament diode balanced noise generator. In addition, there was an arrangement which could periodically replace the aerial with a cold resistor of the same value as the input resistance of the receiver. It was thus possible to keep an adequate check on the overall stability of the equipment.

Method

The principal lobe of the aerial scans a portion of the sky about 40° wide in N-S and 30° in E-W planes centred around the zenith once every day owing to the diurnal rotation of the earth about its axis. The cosmic radio noise power received on the surface of the earth from the zenith sky will vary with its variation with sidereal time. It is, therefore, necessary to know the intensity of the cosmic noise at different sidereal times at a position outside the earth's atmosphere. Fig. 1 represents an extrapolated curve of intensity of cosmic noise at 25 Mc/s. against sidereal time. All the records taken during the year were utilized to develop this curve. It was necessary to average the power received from different portions of the sky at times when the ionospheric influence on the cosmic noise was at a minimum or negligible. Such conditions usually occurred between 03 and 06 hrs. local time and when the critical frequency was less than 8 Mc/s. On this basis, records were chosen and the maximum intensity for each sidereal hour, which could be repeated with an accuracy of ±5 per cent, was taken to be the 'standard' or 'unabsorbed' intensity of the cosmic noise at that sidereal hour. Now if one compares any day's record with this 'standard curve' then one can calculate the attenuation produced in the ionosphere. Our method of analysis consists in noting the intensity of cosmic noise at a local hour, finding the corresponding sidereal time, getting the extra-terrestrial intensity from the curve and then calculating the absorption. The total attenuation of the cosmic noise by the ionosphere is then given by the ratio, expressed in decibels, of the observed power

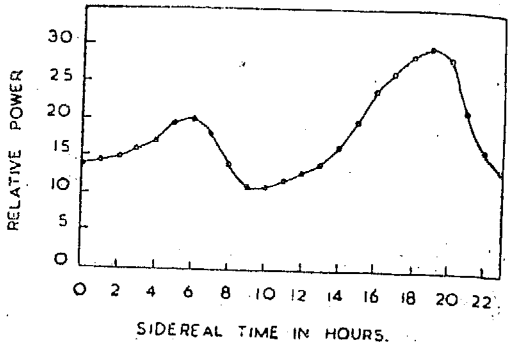

Fig. 1—Cosmic Noise Power Outside the Atmosphere (on 25 Mc/s.) with the Antenna used at Ahmedabad

Table 1—Absorption During Different Seasons

Place	Frequency Mc/s	Year	Lat.	Long.	Maximum Daytime Attenuation, db. Summer	Equinoxes	Winter
Hornsby	18.3	1950-51	34°S	151°E	1.3	0.8	0.9
Ahmedabad	25.0	1957-58	23°02′N	72°38′E	3.4	5.1	4.2

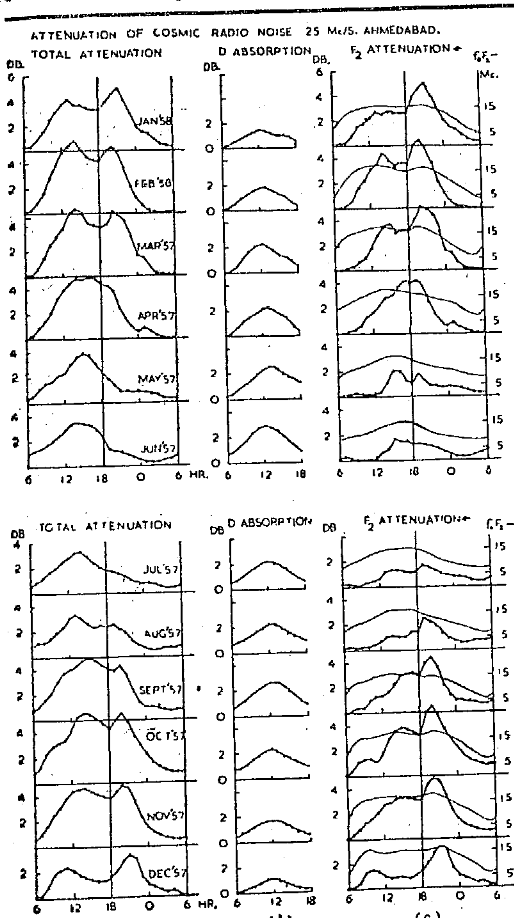

Fig. 2—Monthly Mean Hourly Values of (a) Total Attenuation, (b) D Absorption and (c) F_2 Attenuation (Also Median Values of $f_0 F_2$)

Po, to the power *Ps*, that would have been observed, had there been no ionospheric attenuation.

Total attenuation

Fig. 2(a) represents the monthly mean hourly values of the total ionospheric attenuation in decibels produced in the different ionospheric regions and possibly also in the region laying beyond the level of maximum ionization of the F_2 region, which is normally inaccessible. Mitra and Shain[3] have shown that most of the absorption occurs in D and F_2 regions while E, E_s and F_1 contribute very little to the absorption. It is evident from the figure that the total attenuation exhibits a significant diurnal and seasonal variation. The general trend of variation in the absorption for each month is that, a minimum occurs sometime before sunrise and then it goes on increasing till a maximum is reached in the afternoon usually before 1400 hrs. local time. December 1957 was an exceptional month in which the maximum daytime absorption occurred in the forenoon. Afterwards, the attenuation has a tendency to decrease till sunset. The total attenuation for different months after sunset shows two distinct types of trend, one in which the attenuation increases after sunset till a maximum is reached sometime between 20 and 22 hrs., followed by a continuous decrease for the rest of the night, and another which shows only a steady decrease throughout the night. The months of January, February, March, September, October, November and December belonged to the former group showing a pre-midnight maximum and April, May, June, July and August fell in the latter group which showed steady fall in absorption throughout the night. The pronounced pre-midnight peak in the total attenuation is thus peculiar to winter and equinoctial months, while it is suppressed during summer months. It is worthwhile to compare maximum daytime attenuations observed at Hornsby, Australia and at Ahmedabad, India.

Table 2—Lag in Response of D Region to Ionizing Radiation

	1958		1957									
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Delay in min.	22	17	24	31	36	41	31	30	28	29	32	15

Mean delay = 28 min.

Table 3—Noon Absorption

Place	1958		1957									
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Hornsby	—	—	—	—	—	—	0.6	—	0.6	—	1.1	—
Ahmedabad	1.5	1.8	2.2	2.2	2.6	2.7	2.2	2.3	2.6	2.3	1.7	1.2
Ahmedabad, extrapolated for cos $X=1$	2.1	2.2	2.6	2.1	?	?	2.1	?	2.6	2.5	2.1	1.3

Table 4—Value of n For Different Months

Place	1958		1957									
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Ahmedabad	0.9	1.0	1.2	1.0	1.2	1.1	1.0	1.1	0.9	0.9	0.7	0.6
Hornsby	—	—	—	—	—	—	0.5	—	0.9	—	—	1.1

Table 1 reveals that the absorptions observed during the corresponding seasons at these stations are quite different in magnitude. This difference in attenuations can be attributed to (1) the stations are situated at different latitudes and the F_2 critical frequencies are different, and (2) experiments were conducted at different epochs of the solar cycle.

Separation of contributions to absorption due to D and F regions

Our method of separating the attenuations into two components, one mainly due to the D region and the other mainly due to the F region, is identical with that used by Mitra and Shain[3]. Briefly, the total attenuation is plotted against f_oF_2 for each solar hour. The attenuation decreases with decrease in f_oF_2, and the curve is extrapolated to low values of f_oF_2 and zero F_2 absorption. The residual absorption is found to depend on the solar hour and this is taken to be the contribution due to the D region. The extrapolation to low f_oF_2 values becomes less accurate at hours when low values of f_oF_2 are rare, as in the afternoons.

D region absorption

Fig. 2(b) represents the monthly mean hourly values of absorption which occurs mainly in the D region for each month. It is known that the D region absorption is non-deviative in character and is under strong solar control. The absorption is proportional to the product Nv where N is the electron density and v the collisional frequency of an electron. Though N is small at the height of the D region, the large value of v, which increases with the atmospheric pressure, maintains sufficiently high value of the product Nv resulting in heavy absorption. There are occasions when N also increases enormously, for example, at the time of solar flares, which then produce sudden large increases in cosmic noise absorption and shortwave fadeouts. These short-term effects will be reported in a separate communication. Otherwise, N depends on the solar zenith angle; its value increases as the solar zenith angle decreases. Therefore, a roughly symmetrical curve for D region absorption around the local noon is expected. But it has been found that the absorptions observed for the same solar zenith angle before and after the local noon are not equal. The maximum absorption in the D region occurs not at the local noon, but slightly *after* the local noon, and this has been consistently observed for each month. This observation gives supporting evidence to the view that there is a certain amount of 'lag or delay' in the response of the D region to the solar ionizing radiations. This lag in the response is a measure of the sluggishness of the ionosphere. An attempt has been made to measure the amount of delay for each month and is given in Table 2.

For some reason, there is no constancy in the observed lag in the response from month to month. The largest value for the lag was observed to be 41 min. in the month of June which is midsummer in Ahmedabad, and the smallest observed is 15 min. in December which is midwinter. The lag is thus a maximum in summer and a minimum in winter. It is interesting to note that the average lag taken over a year comes to about 28 min. which is in good agreement with the value of 27 min. obtained by Mitra and Shain[3].

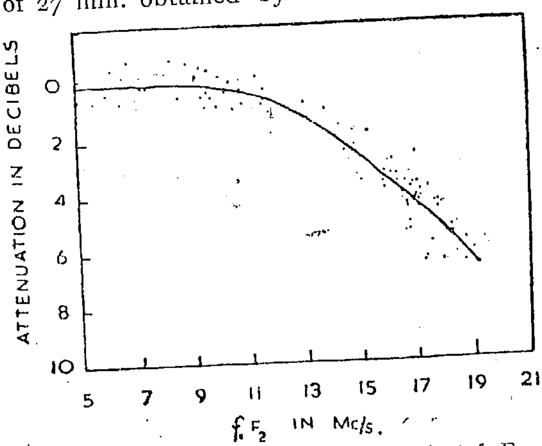

Fig. 3—Mass Plot of Attenuation Against f_0F_2 (Night Observation)

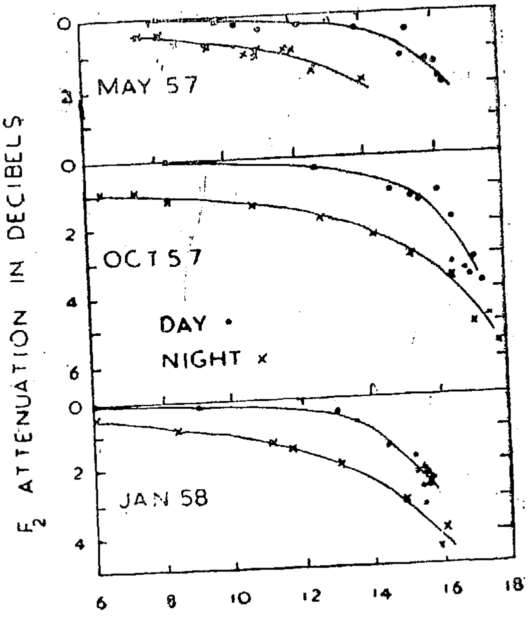

Fig. 4—F_2 Attenuation vs f_0F_2, Day and Night Separately, During Different Months

Warwick and Zirin[6] have also reported an asymmetry in the maximum D region absorption, but it is in the opposite sense, and these authors feel that the delay found in this way is insignificant.

Table 3 gives the noon absorptions in decibels for different months. It is observed that the noon absorption in the D region undergoes considerable seasonal variation.

The maximum of nearly 2.7 db. was recorded in the month of June 1957 and a minimum of 1.2 db. in the month of December 1957. It is known that the diurnal variation of D region absorption is of the form $\cos^n X$. The values of n were determined for each month and are given in Table 4. The extrapolated values of absorption for $\cos X = 1$ for each month are given in the last row of Table 3. In some months, owing to the scatter of the points, no reliable extrapolation for $\cos X = 1$ could be made.

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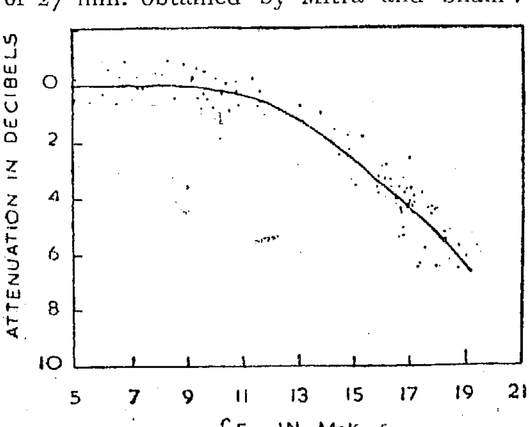
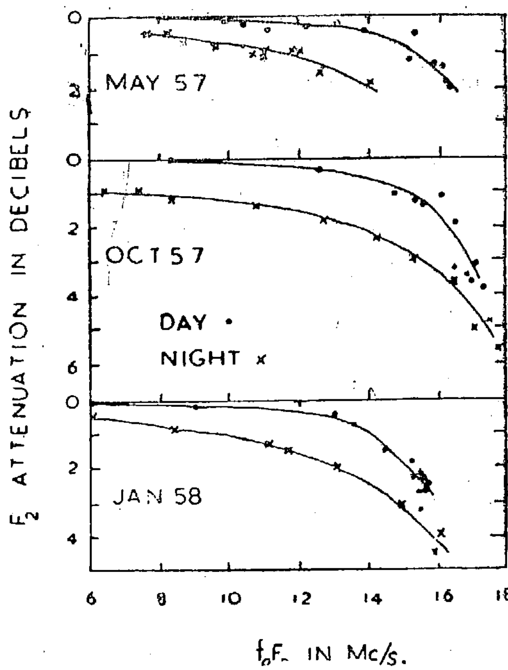


Fig. 3—Mass Plot of Attenuation Against f_0F_2 (Night Observation)



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Averaging over different months, it was found that during summer and equinoctial months n was 1.1 and 1.0 respectively and during winter it was 0.8.

F region absorption

Fig. 2(c) shows the monthly mean hourly values of the attenuation for the different months which mostly occurred in the F region. If the total attenuation is corrected for D absorption then the residual attenuation may be attributed to the F_2 region. The correction has to be applied only during the daytime since D absorption ceases soon after sunset. During the night, whatever attenuation is produced is in or beyond the F_2 region. It is known that the F_2 region absorption is mainly of the deviative type and, therefore, depends on the proximity of the exploring frequency (25 Mc/s.) to f_0F_2.

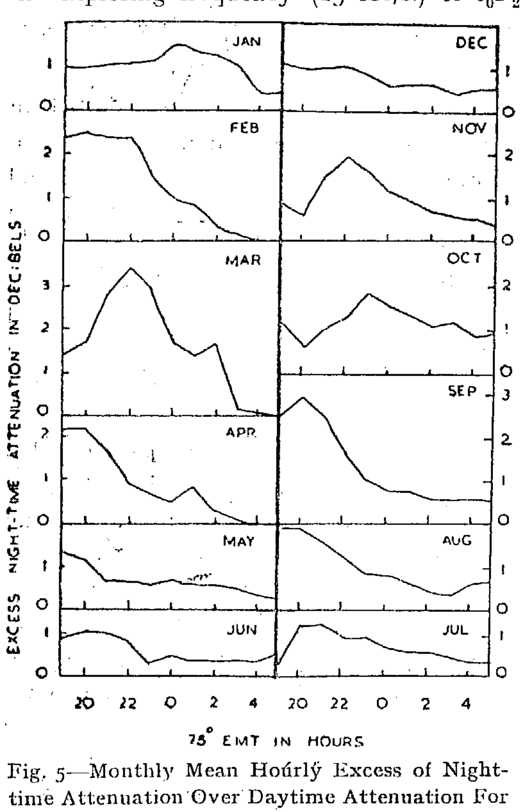

Fig. 5—Monthly Mean Hourly Excess of Nighttime Attenuation Over Daytime Attenuation For The Same f_0F_2

It is also expected that the irregularities in the ionosphere, which cause scintillations of the radio stars, may have, at least, some effect on the intensity of cosmic noise.

Fig. 3 shows a plot of f_0F_2 and F_2 absorption for the nighttime obsevations. It appears that below a particular value of f_0F_2, F_2 absorption is negligible. In general, for f_0F_2 less than 8 Mc/s., F_2 absorption is small. As f_0F_2 increases beyond 10 Mc/s., the absorption rapidly increases. It has been found by other workers that the major component of the total absorption arises in the D region, but that there is an appreciable contribution from the F_2 region. The absorption varies linearly with f_0F_2 according to Blum, while according to Mitra and Shain[3], a curvilinear relation holds over the range 4-8 Mc/s. (for 18.3 Mc/s.). Our observations show that F_2 absorption does not have a linear relation with f_0F_2 and F_2 absorption is by no means less important than D absorption. While the D region absorption was never greater than 3 db. even in snmmer, high F_2 absorptions, exceeding 6 or 7 db., have frequently been observed. Another fact worth noting about F_2 absorption is that during equinoctial and winter months, the maximum nighttime F_2 attenuation exceeded the maximum daytime F_2 attenuation. In general, for a particular value of f_0F_2 it was observed that during all seaons, nighttime attenuation was greater than daytime attenuation (Fig. 4). Fig. 5 shows the excess (night minus day) attenuation at different hours of the night during different months. Such excess attenuation at night was also observed in Australia by Mitra and Shain[3] who have suggested that the ionospheric irregularities in the F region, which produce scattering of radio waves, might be responsible for the occurrence of excess attenuation. These irregularities appear as 'spread' or 'diffuse' echoes on the p'-f records taken by ionospheric pulse soundings.

The data of the ionospheric station at Ahmedabad were analysed for the percentage occurrence of F-scatter echoes and it was found that, during summer and equinoxes when F-scatter echoes were most frequent, large excess attenuations were accompanied by the large frequency of occurrence of F-scatter echoes. The presence of an early night peak in the absorption curve during the winter and equinoxes is, however, difficult to explain solely on the basis of deviative absorption which depends on f_0F_2 and of scattering due to ionospheric irregularities. This will be discussed in a later paper.

Summary

Using cosmic radio noise at 25 Mc/s., the values of total ionospheric attenuation have been found for over a year at Ahmedabad. Since the D and F_2 regions of the ionosphere are the principal attenuating regions, an attempt has been made to separate their respective contributions to the total attenuation. The diurnal and seasonal variations in each case are discussed and it is observed that the F_2 attenuation for high values of f_0F_2 can exceed D absorption. The excess attenuation in the early part of the night are too high to be explained solely on the basis of the deviative absorption of F_2 and scattering due to ionospheric irregularities. This will be discussed in a later paper.

Acknowledgement

One of the authors (R.V.B.) was in receipt of financial assistance from the Atomic Energy Commission during the period of the work.

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COSMIC RADIO NOISE ABSORPTION ON 25 MC/S AND *F* SCATTER

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In a previous communication [*Bhonsle and Ramanathan,* 1958], the authors have reported on the measurements of cosmic radio noise on 25 Mc/s at Ahmedabad over a period of 1 year from March 1957 to February 1958 and have given estimates of the values of the attenuation of cosmic radio noise in the atmosphere. On the assumption that the attenuation occurs mainly in the *D* region and *F* regions of the ionosphere, it was shown that the total attenuation could be divided into two components, a *D*-region and an F_2-region component. On examination of the mean diurnal and seasonal variations, the curves of total attenuation (Fig. 1) showed the following features: (1) minimum attenuation occurs before sunrise; (2) a daytime maximum in the attenuation occurs near or shortly after noon; and (3) a second maximum in attenuation occurs after sunset and before midnight, usually between 20 and 22 hours local time, in the winter equinoctial and months.

Adopting a method previously used by *Mitra and Shain* [1953], *D*-region absorption and *F* attenuation were separately estimated. The *D*-region absorption was found to be directly dependent on solar zenith distance with maximum amplitude in summer and minimum in winter. The deviative *F*-region attenuation was not a simple function of the solar zenith distance; above a certain minimum value of the critical frequency f_0F_2, it increased rapidly with increase in f_0F_2. The F_2 attenuation in the first half of the night often exceeded its maximum daytime value by about 2 db. It was evident that the increase in the value of f_0F_2 in the early part of the night and its nearer approach to 25 Mc/s were inadequate to account for the premidnight peak in F_2 attenuation during winter and equinoctial months. There was some evidence to show that the premidnight peak was connected with *F* scatter. But the occurrence of a rather sharp rise in attenuation shortly after sunset and its reaching a maximum at 21 to 22 hours were puzzling features.

The view that the additional nighttime peak is due to *F* scatter is strongly supported by some new evidence brought out recently by *Bateman and others* [1959] from their observations of *F* scatter during IGY in the Philippines-Okinawa area. They observed anomalous enhancements, during the evening hours, of the signals transmitted at VHF between the Philippines and Okinawa. The enhancements were found to occur with greatest frequency in September and October. They usually lasted several hours, beginning at about 19 hours at the midpoint of the transmission path. The signal intensity usually increased rapidly, then leveled off, and finally dropped back below the normal scatter level around midnight. The first measurements of this anomaly were made over an experimental circuit operating at 36.4 Mc/s between Poro Point, Philippine Islands, and Sobe, Okinawa. A second circuit at 49.84 Mc/s over an almost identical path commenced operating in September 1957. During the year of operation at 36.4 Mc/s, the frequency of occurrence of evening enhancements reached a peak during each equinoctial period. During 1958–1959 at 49.84 Mc/s, however, only the peak in the autumn could be observed. At vernal equinox, there appeared, if anything, to be a minimum.

Bateman and his co-authors have examined the ionospheric data from Baguio, Philippine Islands, and Okinawa ionospheric stations during September 1957, a period of anomalous propagation. No association between the anomaly and *E*-region effects could be detected, but the periods of anomalous propagation did correspond to those of spread-*F* at Baguio and high F_2 critical frequencies at Okinawa. They suggested that the enhanced signal was propa-

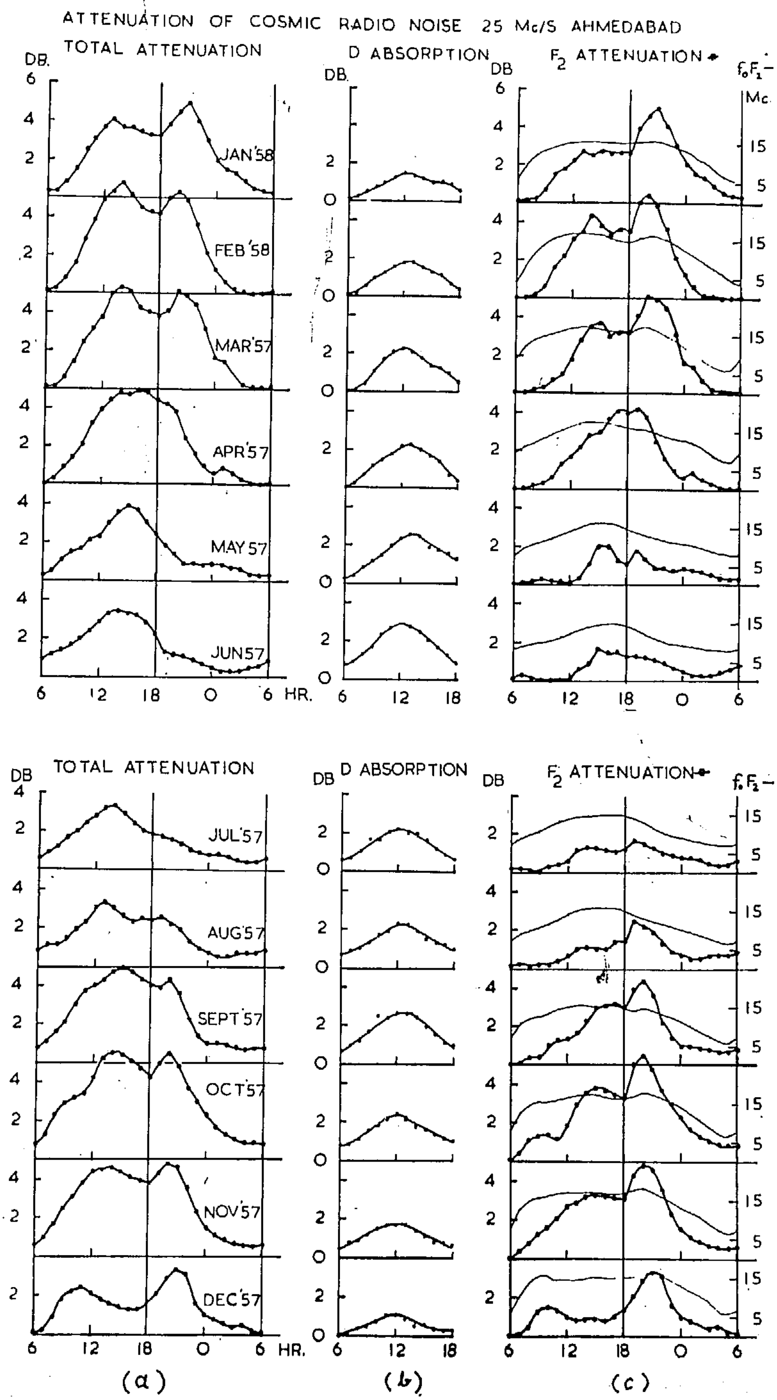

FIG. 1—Monthly mean hourly values of (*a*) total attenuation, (*b*) D absorption, and (*c*) F_2 attenuation (median values of f_0F_2 are also shown by thin lines). (From *J. Sci. Ind. Research, India 17A*, 1958.)

gated via the F region and was enhanced when there was low-latitude spread-F

We are of the view that the anomalous enhancement of scattered VHF signals observed by these authors and the sharp post-sunset increase in the attenuation of cosmic noise observed at Ahmedabad are due to the same physical cause. The agreement in the times of commencement of these two independent effects, in the time taken for reaching their maximum intensity, and in the time of their subsequent decline is very striking. It is physically understandable that ion clouds of appropriate size in the F region can increase the scattered VHF signal strength from a ground transmitter and at the same time attenuate the noise signals received from extraterrestrial noise sources. Seasonal variation of spread-F echoes at Ahmedabad shows a maximum in equinoxes in high-sunspot years and also shows a negative correlation with magnetic activity [*Kotadia and Ramanathan,* 1959]. It may be mentioned here that the cosmic noise absorption on 25 Mc/s at Ahmedabad decreases markedly on days of magnetic storms, a fact that can be correlated with the known absence of F scatter on magnetically disturbed days in low latitudes.

One of the authors, R. V. Bhonsle, is the recipient of a Senior Research Fellowship from the Council of Scientific and Industrial Research, Government of India.

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CHAPTER V

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CHAPTER V

STUDY OF SOLAR FLARES USING COSMIC RADIO NOISE ON 24 MC/S AT AHMEDABAD

1 - INTRODUCTION

A solar flare is a sudden brightening of a part of the sun's surface accompanied by enhanced emission of wave and particle radiations. Large flares consist of a complex pattern of "white-hot" filaments which reach their maximum intensity five or ten minutes after their first appearance and then decay within the next hour or two. Smaller flares are associated with minor bright patches, usually without any filamentary structure. Flares are classified on a visual scale of importance from class 1 (smallest) to class 3 (largest), a higher 3+ being reserved for flares of exceptional area and intensity. In Table I are listed some of the characteristics of flares of different classes, such as average durations, areas and intensities.

The enhanced light emitted by a flare is made up chiefly of individual spectral lines. The emission lines of hydrogen and the H and K lines of singly-ionized calcium are prominent. The Lyman α line (1,216) of hydrogen and the helium line at 584 Å are also enhanced. Rocket observations of the spectra of flares show that, they emit X-rays and with the increase in size of the flare, increasing amounts of X-rays of the shortest wavelength are emitted (Friedman et al[47]). Flares not only emit light; they also throw large quantities of ionised matter. Outward velocities of the order of 1000 Km/sec are often acquired by this moving gas.

Table 1 (After Ellison[46])

Flare class	Average duration in min.	Area in millionths of sun's hemispherical *surface.	Approximate line-width of H α in Å at maximum brightness.	Approximate central intensity of H α at max brightness as a fraction of the level of the continuous spectrum
1	17	100-300	2-4	0.8-1.75
2	29	300-750	4-6	1.75-2.1
3	62	750-1200	6-8	2.1-2.4
3^+	$\sim$ 180	> 1200	> 8	> 2.4

* 1 millionth of the sun's hemisphere = 1.17×10^6 sq.miles = 3.04×10^6 sq.Km.

2 - TERRESTRIAL EFFECTS OF SOLAR FLARES

The wave radiations, irrespective of their wavelength take about 8.5 min to reach the earth. The particles lag behind and arrive at various intervals depending on their speeds.

The waves cause what we refer to as "simultaneous" effects and the particles give rise to delayed effects.

The main effect of the flare radiations is to produce extra-ionisation in the D-region of the earth's atmosphere at a height of 60-90 Km above the ground. It is this increased supply of electrons which brings about the sudden ionospheric disturbances (SID's). The SID's cause following effects :

i) Magnetic crochets (conductivity effect).

ii) Shortwave radio fade-outs (absorption effect).

iii) Sudden enhancements of atmospherics on very low frequencies (improved reflectivity of D-region).

iv) Sudden phase anomalies of very long radio waves (lowering of D-region).

v) Sudden cosmic noise absorptions (SCNA's)(partial absorption effect).

That cosmic radio noise suffers an additional absorption during an SID was first shown by Jansky[49]. Shain and Mitra[50] compared their results on the absorption of 18.3 Mc/s cosmic radio noise with sudden phase anomalies of very long radio waves and showed that an increase of 1 db in the absorption of 18.3 Mc/s radiation passing once through the ionosphere was probably associated with an SPA of size about 200 degrees at 16 Kc/s.

3 - SUDDEN COSMIC NOISE ABSORPTIONS (SCNA's) OBSERVED AT AHMEDABAD FROM 23 FEBRUARY 1956 TO 8 AUGUST 1960

Soon after the cosmic radio noise recording equipment on 25 Mc/s was installed at Ahmedabad in 1956 for measuring ionospheric absorption, the great cosmic-ray-producing solar flare on 23 February 1956 was detected as sudden cosmic noise absorption (SCNA). Its characteristics and associated ionospheric effects at Ahmedabad have been published. (Ramanathan and others[14], reprint enclosed). Later, the author[13] has discussed the characteristics of 80 SCNA's on 25 Mc/s observed at Ahmedabad from February 1956 through September 1958. (Reprint enclosed). The SCNA's have been classified qualitatively into four types; Type A, Type B, Type C and Type D. The SCNA's of type B were most common. The most frequent value of maximum absorption (i.e. size) produced during SCNA's was between 1 and 2 db and their number decreased with increase in size. The time of growth of SCNA's was of the order of 5 min which was in good agreement with that found by other workers, but the durations observed at Ahmedabad were markedly longer, as compared to durations of SPA's of 16 Kc/s and SCNA's of 18.3 Mc/s. There was an obvious tendency for the duration to increase with increase in size.

The SCNA's which have occurred during the period September 1958 to August 1960 have also been similarly analysed and they are listed in this chapter. During this period only

15 SCNA's were recorded. The rate of incidence of SCNA's seems to have considerably decreased with decreasing solar activity.

4 - COMPARISON OF THE SOLAR FLARE ON JULY 29, 1958 AT DIFFERENT LATITUDES

The effects of solar flare which occurred on July 29, 1958 at 03 hr U.T. were observed simultaneously at Ahmedabad, College and Barrow in Alaska and at Thule in Greenland. Since these stations are widely separated in latitude, it is interesting to compare the characteristics of the SCNA's and their after-effects at these places. At the high latitude stations, the cosmic noise observations[48] on 27.6 Mc/s were made with relative ionospheric opacity meters (riometers). At Ahmedabad, they were made with a total-power type radiometer operated at 25 Mc/s.

Fig.1 shows the relevant portions of the cosmic noise recordings made at these stations. The sudden cosmic noise absorption reached its maximum value within about 7 min after the beginning of solar flare at Ahmedabad. The maximum values of absorption observed at Ahmedabad, College, Barrow and at Thule were 10 db, 6.4 db, > 1.9 db and 1.3 db respectively. Thus it is clear that in this instance, the maximum absorption was recorded at low latitude and the absorption decreased progressively at higher latitudes.

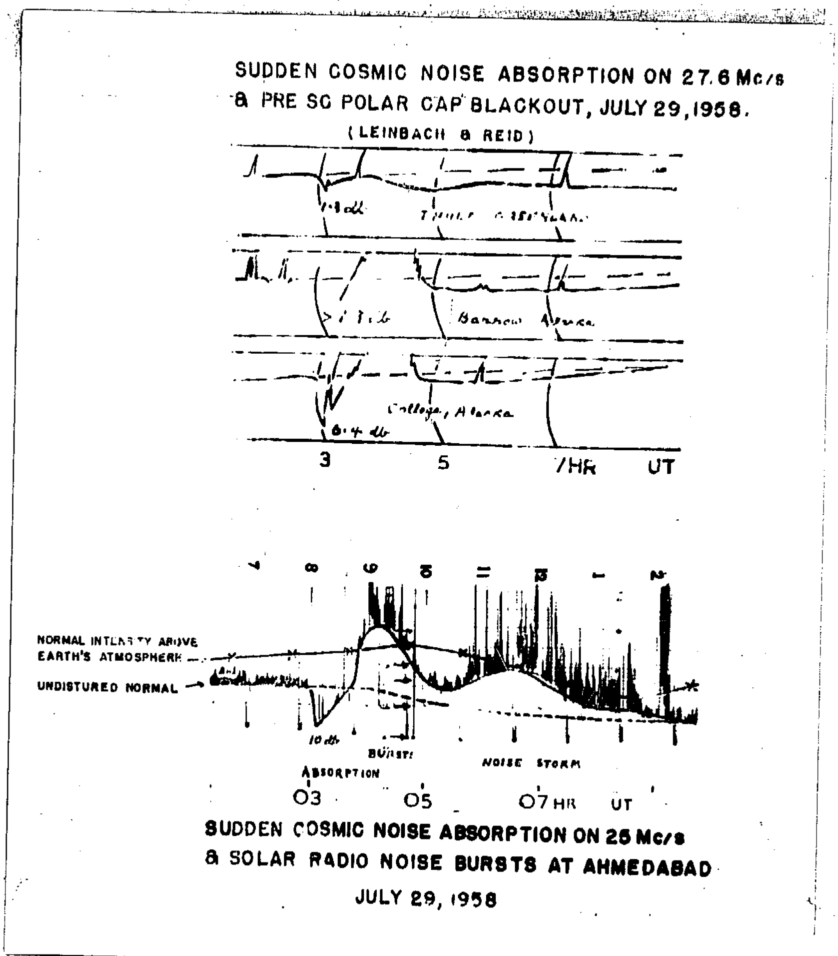

Fig.1. Relevant portions of cosmic noise recordings showing SCNA and solar radio noise bursts on July 29, 1958 recorded at different stations.

The SCNA's are supposed to be the effect of low level ionization in the D-region due to the incidence of solar X-rays in wavelength region (λλ 2 - 8 Å) emitted during the flare. The dotted line on each record shows the normal quiet day variation. The ratio of the quiet-day intensity at any time to the observed intensity at the same time, when expressed in decibels, yields the amount of absorption. Intense solar bursts of noise were emitted a little after the SCNA had reached its maximum size. It took nearly 40 min to recover to the quiet-day value but this is probably an underestimate because of the uncertainty due to the presence of strong radio emissions from the sun. At 0345 hr a long duration but fluctuating type of solar radio burst began and further reliable measurements of absorption became impossible. This disturbance was also evident on the recordings at College and Barrow but was minor at Thule. This long duration burst which began at 0345 hr U.T. seems to have ended by about 05 hr U.T. At Ahmedabad, since our aerial is directed towards the zenith and it was summer, the sun was almost overhead in the noon. The noise-storm on the sun was in progress and its radiation was more intense than the cosmic noise background. Hence the base level of cosmic noise was lifted above its normal value and absorption measurements became impossible till about 09 hr U.T. The continuous curve shown on the Ahmedabad record is the extrapolated intensity of cosmic noise outside the earth's atmosphere. At about 0330 hr U.T., the Thule record began showing a gradual increase in absorption and reached its maximum at about 0445 hr U.T. and remained at that level for the rest of the time. A similar trend was observed after about 05 hr U.T. at Barrow and College but with decreasing amplitude. (Leinbach and Reid[48]).

Reid and Leinbach[37] have recorded 24 such events in the period from May 1957 through July 1959. The increased absorption after the end of a solar flare was explained by Reid and Collins[38] in terms of low energy cosmic rays consisting of protons in the energy range 3 to 50 MeV. It was noted by Little and Leinbach[12] that after the great cosmic-ray-producing flare of February 23, 1956, very strong absorption occurred in high latitudes for about three days. This has been discussed in detail by Bailey[51] who also observed strong absorptions on VHF forward ionospheric scatter in the Arctic.

5 - CHANGES IN ATMOSPHERIC IONISATION ASSOCIATED WITH SOLAR FLARES

Nicolet[52] suggested that the formation of the normal D-region could be explained by photoionisation by Lyman alpha, and Mitra[53] extended this idea by suggesting that the enhancement of Lyman alpha radiation during solar flares was responsible for the increased D-region ionisation. Observations of SPA's show that the reflecting ceiling for long waves is lowered by about 15 Km during 3⁺ flares. The ionisation of a substance like NO by Lyman alpha seems insufficient to produce such a large lowering of the base of the D-layer. According to Friedman and Chubb[47], if the lowering of the D-region were due to Lyman alpha, its intensity in large flares should increase by a factor 10^5. This is highly improbable. The alternative view which is now generally accepted, and confirmed by rocket observations of flare spectra, is that, the solar flares emit X-rays and with increase in the size of the flare, increasing amounts of X-rays of the shortest wavelengths ($\lambda\lambda$ 3Å - 2Å) are emitted. These rays penetrate the atmosphere down to 70 Km causing ionisation of all components of atmospheric air.

We have very little information about the height distribution of the extra-ionization associated with the solar flare. Gardner[54] and Gardner and Pawsey's[29] studies of the partial reflections of long waves from the lower ionosphere confirm the existences of two partially reflecting regions, one near 70 Km and another near 90 Km. Later, Gardner[54] showed that even during SID's, this grouping of echo-heights is maintained. He concluded that during an SID, most of the absorption of the E echo took place between 85 Km and the E reflection level. Morris[55] studied the effect of SID's on radio waves reflected from and transmitted through the ionosphere. The results of simultaneous measurements of the phase changes on waves of frequencies 2-6 Mc/s indicated that the effects were due to an increase in electron density which extends above the maximum of the E layer and possibly upto 150 Km. Simultaneous measurements of increases in absorption in the frequency range 2-24 Mc/s show that there is usually an important increase in absorption in the lowest regions of the ionosphere where $\nu = 10^7$ sec^{-1} (at a height of about 65 Km). At times, the level extends down to about 50 Km where $\nu = 10^8$ sec^{-1}. This conclusion is consistent with the observation of Friedman[47] that in SID's there is an appreciable flux of X-rays of wavelengths as short as 1-2 Å.

Table II

List of SCNA's recorded at Ahmedabad on 23 Mc/s from December 1958 to August 1960.

Date	Type of SCNA	Time of beginning U.T.	Duration in min.	Time of half recovery in min.	Maximum absorption in db.
1958					
December					
13	B	0315	45	15	1.2
21	B	0545	?	30	2.8
1959					
June					
11	A	0509	60	20	4.8
July					
14	B	0525	?	?	5.0
November					
30	A	0250	45	15	2.3
1960					
April					
3	B	0903	30	7	1.3
2	B	0525	60	15	2.1
7	A	0150	30	5	1.5
May					
30	A	0740	10	5	0.3
June					
2	B	0340	90	30	6.0
8	A	0745	40	25	1.2
13	B	0700	45	?	?
23	B	0420	75	30	2.0
August					
7	B	0725	60	7	2.3

6. REPRINTS

i) THE GREAT SOLAR FLARE OF 23RD FEBRUARY OF 1956 AND ASSOCIATED IONOSPHERIC EFFECTS AT AHMEDABAD BY RAMANATHAN, K.R., BHONSLE, R.V., KOTADIA, K.M. AND RASTOGI, R.G.

ii) STUDY OF SOLAR FLARES USING COSMIC RADIO NOISE ON 25 MC/S AT AHMEDABAD (23°02'N, 72°38'E) BY BHONSLE, R.V.

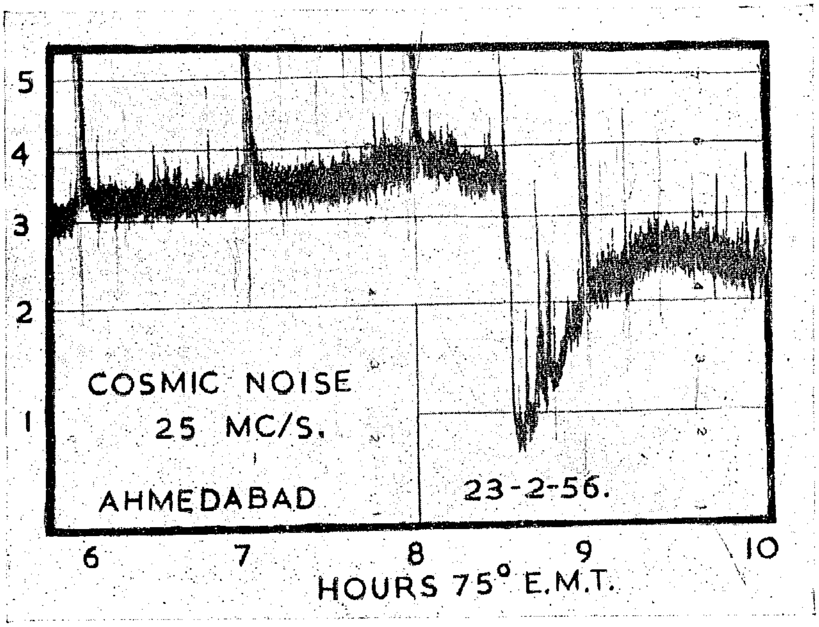
5
4
3
2
1
COSMIC NOISE
25 MC/S.
AHMEDABAD
23-2-56.
6
7
8
9
10
HOURS 75° E.M.T.

FIG. 1

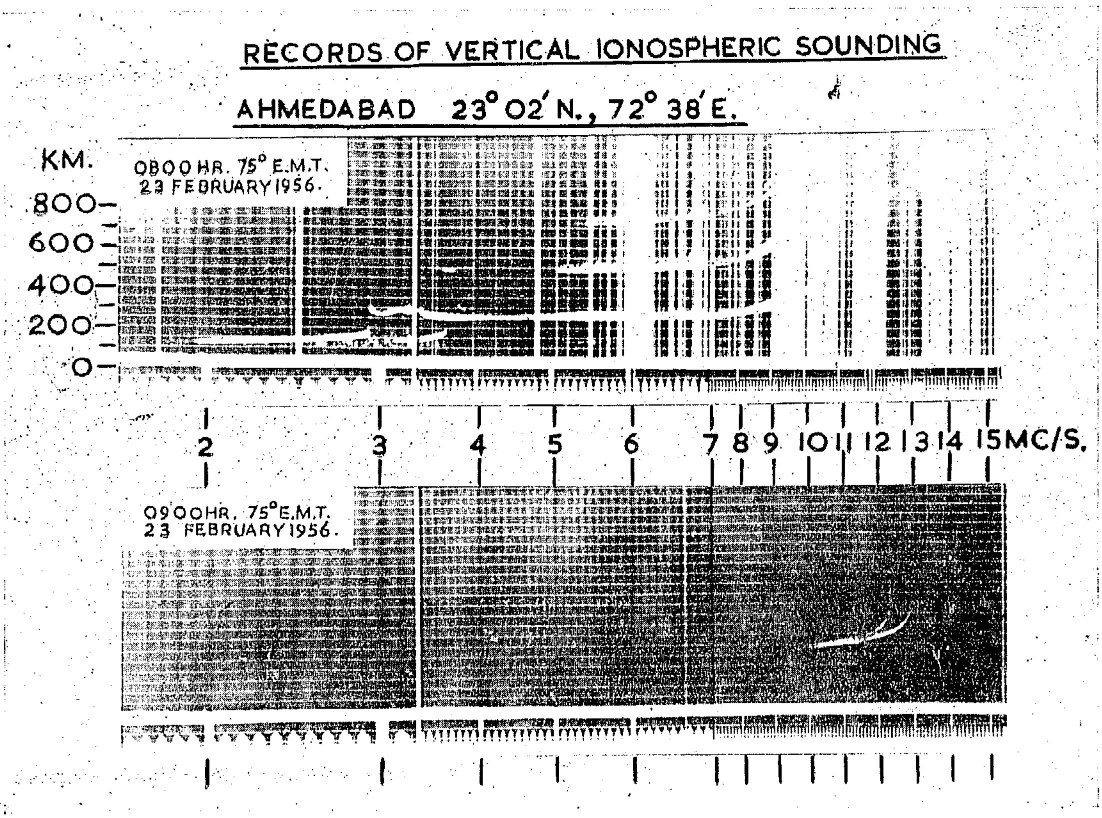
RECORDS OF VERTICAL IONOSPHERIC SOUNDING
AHMEDABAD 23° 02′ N., 72° 38′ E.
KM.
0800 HR. 75° E.M.T.
23 FEBRUARY 1956.
800
600
400
200
0
2
3
4
5
6
7 8 9 10 11 12 13 14 15 MC/S.
0900 HR. 75° E.M.T.
23 FEBRUARY 1956.

FIG. 3

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THE GREAT SOLAR FLARE OF FEBRUARY 23, 1956 AND ASSOCIATED IONOSPHERIC EFFECTS AT AHMEDABAD

By K. R. Ramanathan, F.A.Sc., R. V. Bhonsle, K. M. Kotadia and R. G. Rastogi

Received April 27, 1956

For some months now, the Physical Research Laboratory, Ahmedabad, has been recording continuously cosmic radio noise from the vertical sky on a frequency of 25 Mc/s, using a broadside collinear array of 16 dipole aerials, covering an angle of 37° in N-S and 30° in E-W directions. A Hammerlund Communications receiver with its output amplified by a differential D.C. amplifier, and calibrated by a diode noise generator, is used to record the noise intensity on an Evershed recording milliammeter. On 23–2–1956, an exceptionally large sudden absorption of cosmic noise (SCA) was observed. It commenced at 0831 hours 75° E Meridian Time, (0331 hours G.M.T.), reached its maximum at 0838 hours and died out by about 0930 hours. The sudden increase in absorption took place in two stages, the second and larger increase being at 0833 hours. A photograph of the record is reproduced in Fig. 1.

2. In Fig. 2, the noise record of 23–2–1956 is compared with those on three neighbouring days. By interpolating the "undisturbed" curve of variation on 23–2–1956, and expressing the differences in intensity at different times from the undisturbed values, it appears that the intensity of cosmic noise at the time of maximum absorption was 6·5 decibels below normal. This value may be compared with the highest absorption of 7 db. noted by Dr. C. A. Shain and Dr. A. P. Mitra (1954) at 18·3 Mc/s during a solar flare on April 20, 1951, in Australia.

3. By the courtesy of the Chief Engineer, Overseas Communication Service, India, we give below the observations on the fade-outs of long-distance communication recorded by the Beam Wireless Station, Poona, on 23–2–1956.

Table I

Radio-communication fade-outs recorded by Beam Wireless Station, Poona, on 23–2–1956

Circuit	Frequency (Kc./s.)	Time of Fade-out
Osaka, Japan	18,355	0835 to 1015 hours 75° EMT. Weak signals Up to 1045 hours
China	20,120	
Melbourne	18,700	
Bangkok	18,200	
Indonesia	18,135	0835 to 1915 hours
Kabul	7,788	0835 to 1915 hours

The equivalent vertical incidence frequencies for one- or two-hop reflections for an assumed height of reflection of 300 km. are all below 7 Mc/s.

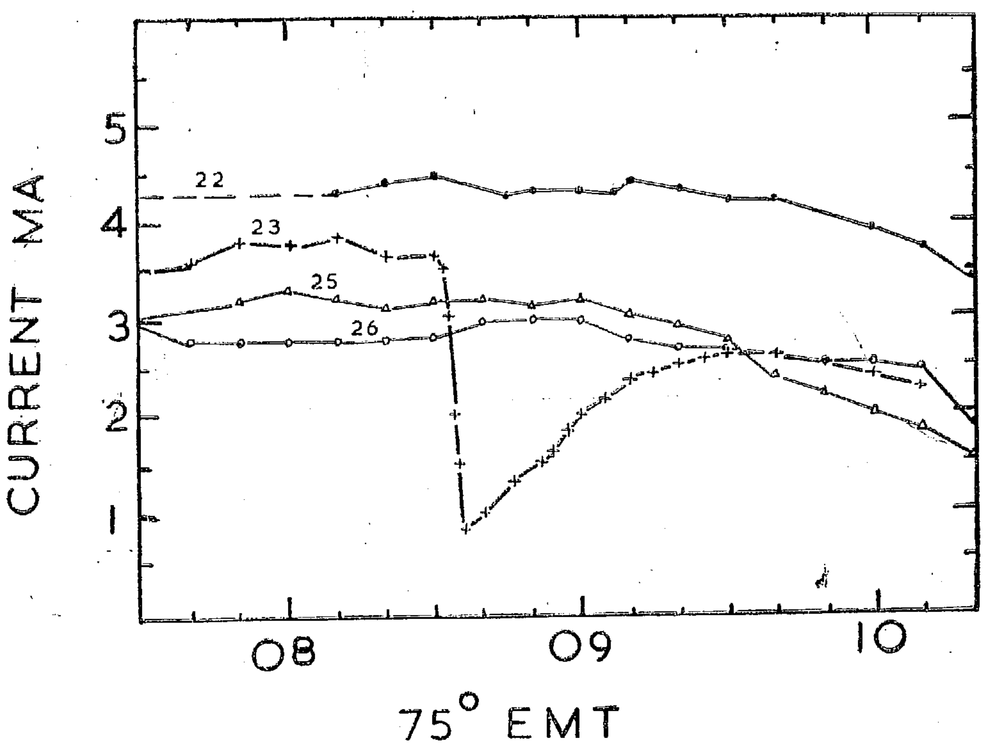

FIG. 2. Cosmic Radio Noise, 25 Mc/s, 1956 Feb. 22, 23, 25 and 26, Ahmedabad.

4. The hourly records of the vertical pulse soundings of the ionosphere made in the laboratory showed that the reflections were normal at 0800 hours 75° EMT, but at 0900 hours, there was a black-out of all vertical reflections up to 10 Mc/s (Fig. 3). It will be seen that at the same hour, the reflections of radio waves emitted by broadcasting stations were not visible even at 15 Mc/s.

All this, and most significant of all, the definite significant increase in cosmic-ray meson flux recorded at the low geomagnetic latitudes of Ahmedabad, Kodaikanal and Trivandrum, mark out this solar flare as one of exceptional magnitude and character (*Ibid.*, Sarabhai *et al.*).

5. It is known that these sudden short-wave absorptions (SCA's) follow solar flares and are associated with sudden phase changes of ionospheric reflections of long radio waves and magnetic "crotchets". The Cavendish workers (Bracewell, 1952; Weekes, 1955) give reasons for thinking that the additional

short-wave absorption occurs in a layer well below the normal E layer, at a height of about 75 km. They have made the suggestion that during strong flares, the sun emits some radiation (probably in the short X-ray region) which penetrates the F and E layers and ionises some constituent of the atmosphere which exists normally in small quantities at about 75 km. Nothing, however, is *definitely* known either about the frequency of the radiation or the atmospheric constituent reponsibile for the increased low-level ionisation.

6.. It may be of some interest to record here another strong cosmic radio noise absorption which occurred on 10–3–1956. It commenced at 0945 hours, reached its peak at 1005 hours and died out at about 1110 hours 75° EMT (Fig. 4). The maximum absorption in this instance was 3·6 db. The hourly ionospheric vertical soundings at Ahmedabad showed normal reflections at 0850 hours, complete absorption up to 9 Mc/s at 0955 hours and absorption

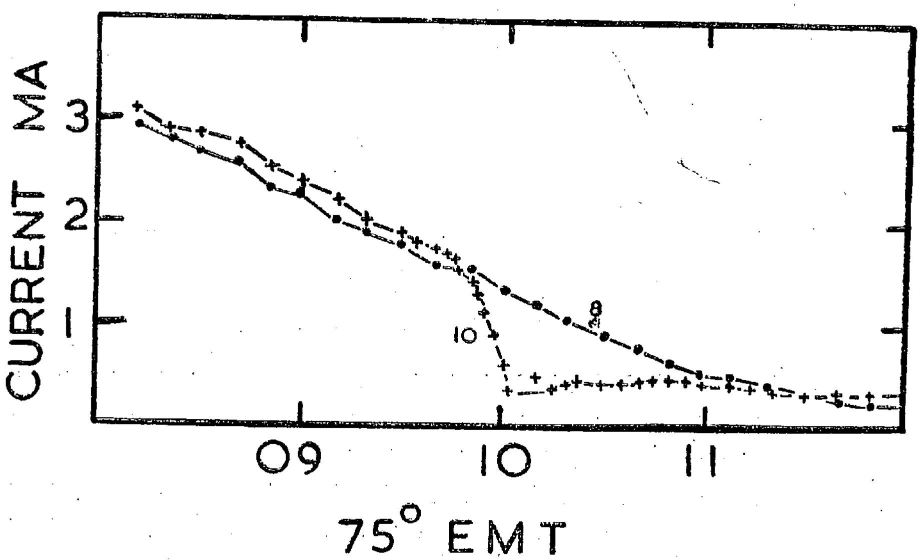

FIG. 4. Cosmic Radio Noise, 25Mc/s, 1956 March 8 and **10**, Ahmedabad.

up to 5 Mc/s at 1055 hours. No cosmic ray effects were observed at Indian latitudes.

As we are now on the up-grade of solar activity, more flares of varying degrees of intensity may be expected in the next two or three years and careful monitoring of all the phenomena associated with them, will be of great value.

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STUDY OF SOLAR FLARES USING COSMIC RADIO NOISE ON 25 Mc./s. AT AHMEDABAD (23 °02′ N., 72° 38′ E.)

BY

R. V. BHONSLE

interval over which the flare appears brighter than the background. The principal effect of the flare-radiations on the ionosphere is to enhance the electron concentration in the D-region. This causes short wave radio fade-outs, sudden cosmic noise absorptions (SCNA) and sudden phase anomalies in low frequency wave propagation (SPA). Shain and Mitra[3] have analysed the SCNA's observed on 18·3 Mc./s. in Australia and compared the results with the observations of SPA's on 16 Kc./s. observed by Bracewell and Straker[4] in England. They showed that an SCNA of maximum intensity of 1 db was equivalent to an SPA of size 200°. Ramanathan *et al.*[5] reported on the characteristics of two SCNA'S which occurred on 23rd February 1956 and 10th March 1956; the former was of exceptional intensity and caused cosmic ray increases near the geomagnetic equator (V. Sarabhai *et al.*[6]). Since then, about 80 SCNA's have been recorded at the Physical Research Laboratory, Ahmedabad (23° 02′ N., 72° 38′ E.), India. The present paper gives an analysis of the results. The list of SCNA'S is given in Table IV.

2. AN EXAMPLE OF AN SCNA AND ASSOCIATED IONOSPHERIC FADE-OUT

Figure 1 (*a*) shows the record of an SCNA which occurred on the 27th January 1957 at 1245 hr. 75° EMT. It was characterised by a sudden reduction in the intensity of cosmic radio noise on 25 Mc./s. at the time of a solar flare. The intensity of cosmic radio noise continuously decreased till a minimum was recorded at 1250 hr. The maximum absorption was about 6·5 db. Thereafter, a gradual recovery started and the noise level was normal by about 1330 hr. This is the usual pattern of SCNA's, but the rates of growth and decay vary widely from one SCNA to another. In general, the growth of an SCNA is rapid and the recovery slow. Figure 1 (*b*) shows a sequence of three records of ionospheric pulse reflections taken before, during and after the solar flare associated with the SCNA described above. The first record at 12 hr. shows that the reflections were normal. The second at 13 hr. shows an absence of reflections up to 14 Mc./s. This represents a partial ionospheric fade-out caused by the solar flare. The third record at 14 hr. shows that normal ionospheric reflections had again been established. Intense solar flares usually produce complete radio fade-outs which disrupt wireless communication on short waves for sometime. Cosmic noise-fade-out on 25 Mc./s. is usually of a partial nature and during most solar flares, measurable intensity of cosmic noise can be observed. There have been a few instances when there was almost complete fade-out on 25 Mc./s., but such occasions are rare. Since cosmic noise records are continuous, it is possible to study the progress of solar flares even when the sun is obscured owing to cloud.

3. Classification of SCNA's

As seen from the cosmic noise records at Ahmedabad, it has been found to be convenient to classify SCNA's into four types; examples of them are shown in Fig. 2, where the excess absorption due to flare expressed in db is plotted against time. An SCNA of type A is characterised by a sudden

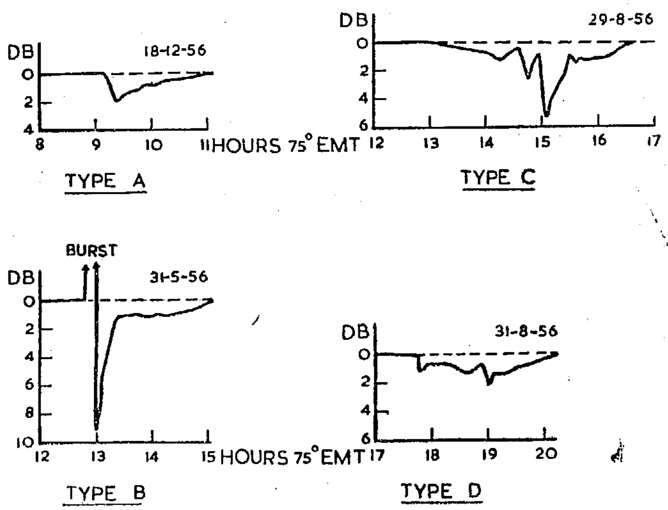

Fig. 2. Four types of SCNA's. Type A, Type B, Type C and Type D.

increase in absorption, an SCNA of type B is accompanied by bursts of solar radio noise, type C is associated with multiple or extended solar flares, and an SCNA is said to be of type D when it is observable at a time when the sun is low in the sky. The SCNA's were classified on this broad qualitative basis, irrespective of the maximum intensity, or in other words, of the maximum absorption produced by the ionosphere. SCNA's of type B are the most common. For a quantitative study of SCNA's, one has to examine the records in detail by noting the times of start, and growth, their duration and "size". The maximum absorption during an SCNA expressed in db is termed the "size" of an SCNA. Absorption at a given time during an SCNA is the ratio, expressed in db, of the observed power to the power that would have been received at that time, had there been no SCNA. While the times of start and growth of SCNA's can be read with an accuracy of ± 1 min., the duration cannot be estimated with equal precision. The slow rate of recovery towards the end of an SCNA is mainly responsible for this. However the time taken by an SCNA to recover to half the size can be measured with fair accuracy.

4. INTENSITY OF SOLAR FLARE AND SIZE OF SCNA

Braçewell and Straker[4], and Shain and Mitra[3] from their studies of SPA's of 16 Kc./s. and SCNA's of 18·3 Mc./s., conclude that in general, solar flares of classes 3, 2 and 1 were associated with intense, moderate and small SPA's and SCNA's. It has been observed from our studies of SCNA's of 25 Mc./s. that solar flares of class 3 or 3+ are usually associated with SCNA's of large size but since the size of an SCNA depends not only on the intensity of the flare as determined optically but also on the sun's zenith distance at the time of the flare, a solar flare of class 1 may cause an SCNA of size greater than that caused by a class 2 solar flare.

5. CHARACTERISTICS OF SCNA'S

(*a*) *Size.*—Figure 3 represents the frequency distribution of the sizes of SCNA's of 25 Mc./s. at Ahmedabad. It is clearly seen that the mode of

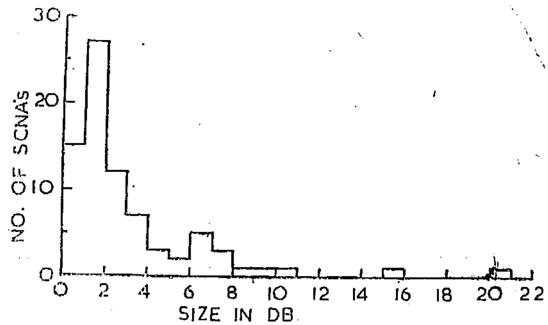

FIG. 3. Frequencies of SCNA's of different intensities.

the distribution lies between 1 and 2 db and that the number of SCNA's falls off rapidly with increasing size. Actually what one might expect is that the number of SCNA's of the smallest size would be the largest. But in practice, this has not been found to be so. It is possible that a few SCNA's of size smaller than 1 db have been missed owing to natural or artificial interference. Besides, it has been observed that all small flares are not capable of causing SCNA's or it may be that, an SCNA once started, always grows to a certain minimum size. A similar type of distribution, in the case of SPA's, was observed by Bracewell and Straker. Shain and Mitra succeeded in showing that the cumulative frequency distribution of SCNA's obeys the following relation,

$$dn = ks^{-p} \ ds \tag{1}$$

where n is the number of SCNA's in a small range 'ds' of s, where s is the size and k is a constant. They found that a value of p near about 2 gives the best fit. Figure 4 shows the cumulative frequency distribution of the SCNA's of different sizes observed at Ahmedabad on 25 Mc./s., that is, the percentage

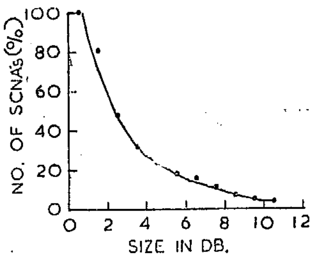

FIG. 4. Cumulative frequencies of SCNA's.

of the total number of SCNA's having a size equal to or greater than a defined amount. Even though the sizes of SCNA's observed at Ahmedabad are larger than those observed in Australia by a factor of about 3, the above relation (1) with p near about 2 still holds.

(*b*) *Time of growth*.—In Table I, the mode, median and quartile values of the times of growth of SCNA's and SPA's are compared. It is evident

TABLE I

Times of growth of SCNA's and SPA's in minutes

Method	Authors	Mode	Median	Quartiles	
				Q_1	Q_3
SCNA 18·3 Mc./s.	Shain and Mitra	..	5	4	9
SPA 16 Kc./s.	Bracewell and Straker	6	7·5	5·5	10·5
SCNA 25 Mc./s.	Bhonsle	5	7	4·7	11·0

that the frequency distribution of the times of growth measured at Ahmedabad agree well with those observed elsewhere. Helen W. Dodson *et al.*[7] attempt to distinguish between sudden short wave fade-outs and gradual short wave fade-outs. According to them, gradual and sudden SID's represent two quite different phenomena. It is possible that the SCNA's of short and long times of growth are associated with sudden and gradual short wave fade-outs respectively.

(*c*) *Duration.*—Table II gives durations of SCNA's and SPA's and summarizes the observations of the other workers. The median and quartile

TABLE II

Durations of SCNA's and SPA's in minutes

Method	Authors	Mode	Median	Quartiles Q_1	Quartiles Q_3
SCNA 18·3 Mc./s.	Shain and Mitra	..	21	15	34
SPA 16 Kc./s.	Bracewell and Straker	30	33	26	48
SCNA 25 Mc./s.	Bhonsle	55	47	27	62

values of duration differ widely at different places. The median value of duration obtained from the observations at Ahmedabad is much larger than those obtained from SCNA's at 18·3 Mc./s. and SPA's at 16 Kc./s. It is interesting that while the times of growth of SCNA's and SPA's are in good agreement, their durations differ. By duration we mean the interval of time between the earliest indication of an SCNA and its end as determined from the appearance of the record. Figure 5 represents a scatter diagram of size

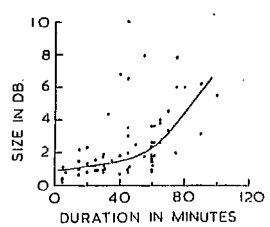

FIG. 5. Scatter-diagram of size and duration of SCNA's.

against duration of SCNA's at Ahmedabad. SCNA's of type C, *i.e.*, multiple or extended ones, are not included in this diagram. There is an obvious tendency for the duration to increase with increasing size of SCNA. In general the SCNA's observed at Ahmedabad take a much longer time to recover than those observed in Australia, and this is probably connected with the difference in the phases of solar activity in which the observations were made.

(*d*) *Ratio* (*Duration/Time of Growth.*)—Waldmeir[8] gave the ratio of the duration of the flare to its time of growth as 5. In Table III a comparison

TABLE III

Ratio (Duration/Time of growth) of SCNA's and SPA's

Method	Authors	Mode	Median	Quartiles Q_1	Quartiles Q_3
SPA 16 Kc./s.	Bracewell and Straker	4	..	3·5	6·5
SCNA 25 Mc./s.	Bhonsle	4·5	4·7	3·5	7·5

is made between our observations of SCNA's with those of SPA's. There is good agreement in the values of this ratio. This means that, on an average, an SCNA lasts for a period which is about five times the period which it takes to grow to its full size.

6. Changes in Atmospheric Ionization Associated with Solar Flares

Nicolet[10] suggested that the formation of the normal D-region could be explained by the photo-ionization by L_α, and Mitra[9] extended this idea by suggesting that the enhancement of L_α radiation during solar flares was responsible for the increased D-region ionization. He assumed that the flare-time enhancement of ionization occurred uniformly throughout the D-region. In the light of later work on low frequency reflections from the lower ionosphere (Gardner[13]) and rocket observation on solar spectra (Friedman *et al.*[12]), flares do not seem to have any perceptible influence on the E and F layers, but the D-layer is very much affected. Observations of SPA's show that the reflecting ceiling for long waves is lowered by about 15 km. during 3^+ flares. The ionization of a substance like NO by L_α seems insufficient to produce such a large lowering of the base of the D-layer. According to Friedman and Chubb, if the lowering of the D region were due to L_α, its intensity in large flares should increase by a factor 10^5. This is highly improbable. The alternative view which is now generally accepted is that, the solar flares emit X-rays and with increase in the size of the flare, increasing amounts of X-rays of the shortest wavelengths (λλ 8Å–2Å) are emitted. These rays penetrate the atmosphere down to 70 km. causing ionization of all components of atmospheric air. Gardner and Pawsey's[11] studies of the partial reflections of long waves from the lower ionosphere confirm the

TABLE IV

Solar flare absorptions tabulated from the recordings of cosmic radio noise on 25 Mc./s. at the Physical Research Laboratory, Ahmedabad, India

23rd Feb. 1956 to 14th Sep. 1958

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min.	Time for half-recovery in min.	Maximum absorption in db
1956 February 23	3+	B	0331	90	22	6·2
March 10	2	B	0450	100	25	5·5
May 30	2+	C, D	0240	180	20	2·1
30	2+	B, C	0940	160	13	8·1
31	3	B, C	0749	50	8	9·2
July 24	..	B	0920	70	5	4·5
25	..	C	0530	20	4	2·0
25	..	C	0550	20	8	0·8
27	..	A	0540	25	7	1·5
27	..	C	0920	50	7	2·3
August 27	1	C	0949	15	7	1·5
27	1	C	1002	60	10	1·2
28	1+	A	0805	80	17	6·0
29	2	A, C	0955	150	20	5·3
September 9	..	A	0745	45	12	6·5

TABLE IV (*Contd.*)

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min.	Time for half-recovery in min.	Maximum absorption in db
November 15	1	B, C	0810	85	8	1·3
18	1	B	0838	55	15	1·8
22	1	A	0855	60	20	1·0
December 17	2	A	1010	30	15	0·8
18	1	A	0405	60	25	1·9
19	..	A, C	0605	95	7	7·6
19	1	A, C	0845	50	17	2·7
20	2	A	0450	55	8	7·9
20	1	A	0635	65	5	3·8
26	2	A	0535	60	5	1·2
27	1	A	0625	30	15	1·9
1957 January 27	..	A	0745	40	10	6·7
February 14	1	B	0422	45	35	1·1
19	..	B, D	0250	5	2	1·1
March 12	..	A	0548	15	5	2·2
April 14	..	A	0536	60	20	1·5
16	3	A	1040	75	30	7·8
20	..	D	0200	15	5	0·7

TABLE IV (*Contd.*)

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min.	Time for half-recovery in min.	Maximum absorption in db
June 4	..	B	0857	70	25	3·4
10	1	B	1048	60	30	2·6
July 1	1+	B	0345	40	8	0·7
4	..	B	0435	60	30	0·9
8	2	B	0538	30	8	1·0
12	..	B	0436	25	15	3·9
16	2	B	0737	45	15	3·5
21	2	D	0135	5	2	0·2
21	..	C	0333	5	2	0·4
21	..	C	0416	5	2	0·3
21	..	B	0704	65	30	2·6
22	..	B	0630	45	20	1·0
29	2	C	0456	50	7	1·1
August 8	2+	B	1122	45	15	1·1
September 1	1	D	0204	20	10	0·7
3	..	B	1024	45	7	2·0
7	2	B	0815	35	7	15·0
15	1	C	0333	75	30	0·9
18	1	C	0630	60	15	0·8

TABLE IV (*Contd.*)

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min-	Time for half-recovery in min.	Maximum absorption in db
19	2+	B	0803	65	22	4·0
21	1+	C	0415	75	20	1·2
October 1	1	B	0653	35	8	1·5
19	2	B, C	0632	90	30	1·4
November 10	2	B	0658	45	15	3·0
17	1+	B	0530	60	15	1·8
23	2	B	0735	60	17	3·6
December 10	..	A	0435	75	27	2·0
15	..	B	0537	7	3	3·8
17	..	B	0737	90	35	3·2
18	..	B	0625	60	22	1·6
19	2	B	0753	60	17	2·4
20	1	A	0545	?	15	1·1
26	1+	B	0917	45	8	0·8
1958 March 11	..	B	0614	15	10	1·0
11	..	B	0717	30	15	1·8
23	3+	B	0955	150	10	20·0
April 2	2	B	0500	20	5	2·3

TABLE IV (*Contd.*)

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min.	Time for half-recovery in min.	Maximum absorption in db
7	..	B	0652	30	7	1·1
May 5	1+	B	0415	33	7	4·3
June 2	..	B	0700	20	7	1·2
3	..	C	0240	25	7	1·2
6	2	B	0437	40	12	1·8
July 29	3	B	0300	45	17	10·0
August 28	2+	B	1022	75	30	6·0
September 14	2+	B	0853	60	25	2·6

Type A .. Sudden increase in absorption.
B .. Sudden burst of intensity followed by absorption.
C .. Absorption due to multiple or extended flares.
D .. Flare at the time of low sun.
Local Mean Time = UT + $4^h\ 50^m$

existence of two reflecting regions, one near 70 km. and another near 90 km. Gardner[13] showed that even during SID's, this grouping of echo-heights is maintained. He concluded that during an SID, most absorption of E-echo takes place between 85 km. and E-reflection level. The course of an SPA and SCNA during a solar flare need not be the same. SPA's depend mainly on the ionization of the lower D-region but SCNA's are affected by the total absorption which is proportional to $\int N\ \nu\ dh$, through the ionosphere where N is the number of electrons per unit volume and ν is its collision frequency. Hence, it is to be expected that SCNA's will take more time to disappear than SPA's.

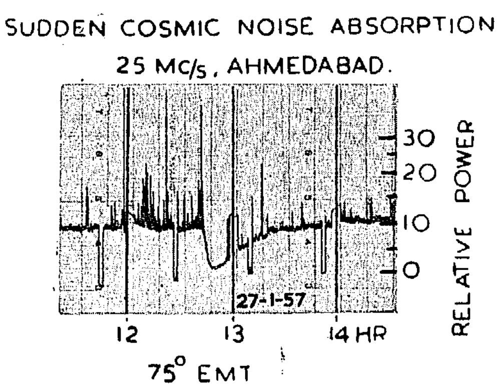
SUDDEN COSMIC NOISE ABSORPTION
25 Mc/s, AHMEDABAD.
30
20
10
0
RELATIVE POWER
27-1-57
12
13
14 HR
75° EMT

FIG. 1 *(a)*

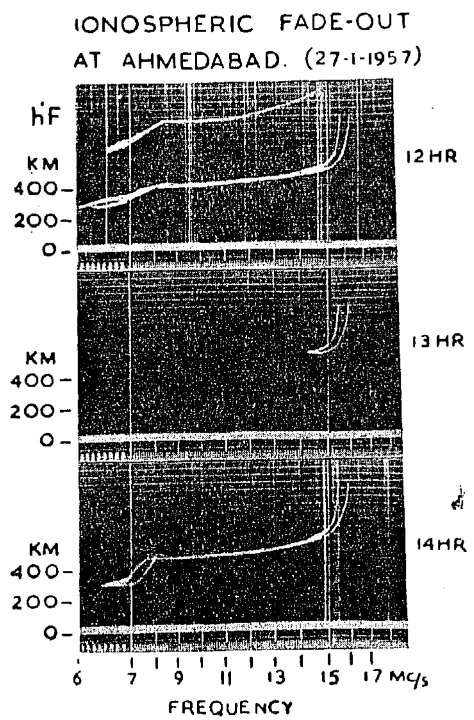
IONOSPHERIC FADE-OUT
AT AHMEDABAD. (27-1-1957)
h'F
KM
400
200
0
12 HR
13 HR
14 HR
6
7
9
11
13
15
17 Mc/s
FREQUENCY

FIG. 1 *(b)*

7. Conclusions

(*a*) SCNA's on 25 Mc./s. observed at Ahmedabad have been classified into four types; Type A, Type B, Type C and Type D. SCNA's of type B are the most common.

(*b*) SCNA's of size between 1 and 2 db are most frequent, and their number falls rapidly with increase in size.

(*c*) The time of growth of SCNA's is generally of the order of 5 min., which is in good agreement with that found by other workers.

(*d*) Durations of SCNA's observed at Ahmedabad is much longer as compared to SPA's. There is an obvious tendency for the duration to increase with increasing size of an SCNA.

Acknowledgements

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CHAPTER VI

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MAGNETIC STORMS AND COSMIC RADIO NOISE ON 25 MC/S AT AHMEDABAD (23°02'N, 72°35'E).

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CHAPTER VI

MAGNETIC STORMS AND COSMIC RADIO NOISE ON 25 MC/S AT AHMEDABAD (23°02'N, 72°33'E)

1 - GENERAL

It is now generally accepted that the magnetic storms are caused by the arrival at the earth of clouds of charged particles emitted by the sun and that the average speed of particles is about 1600 Km/sec from the sun to the earth. Some of the magnetic storms are preceded by some 20-40 hours by a solar flare.

Not every magnetic storm, however, has its origin in a flare, many of the weaker ones have a marked tendency to recur at intervals of 27 days - the solar rotation period- and it is presumed that there are regions on the sun called M-regions which continuously emit streams of particles for fairly long periods. The world-wide storms frequently begin with a sudden commencement which is simultaneous within a few seconds all over the world. In the traces of the horizontal force (H), there is usually an increase above the normal value which lasts for two or three hours in the initial phase of the storm. This is followed by a large decrease in the value of H and this is the main phase. After this, comes a period of slow recovery which may continue for several days.

2 - THE F-REGION OF THE IONOSPHERE DURING MAGNETIC STORMS

Berkner, Seaton and Wells[37] were the first to study the effect of magnetic storms on the ionosphere. They found both at Kensington and Huancayo that the sudden commencement of the severe storm on April 16, 1938 was accompanied by a decrease of electron densities to one-hundredth of their previous value within an hour. Berkner and Seaton[38] later reported similar outstanding changes in the F_2 electron density and height after the SC of the magnetic storm of March 24, 1940. These results indicate that the change in the F-region starts almost simultaneously with the magnetic storms.

It was shown by Appleton, Ingram and Naismith[39] that the mean value of Δf_oF_2 during a magnetic storm varies with the season and latitude, and that there was also an effect on Δf_oF_2 of the local time.

Maeda and Sato[60] have summarised the characteristics of the daily variation of Δf_oF_2. For higher latitudes, including the auroral zone, the great depression of f_oF_2 usually occurs at a time centred on the local noon throughout the year. The duration of depression undergoes a seasonal change. At low latitudes near the equator, an increase of f_oF_2 occurs in every season and depressions are quite rare. In middle latitudes, there are two types of variation of Δf_oF_2. One is the depression type as in the higher latitudes, and the other is the increase of f_oF_2 from noon towards night which is representative of the type found in equatorial latitudes. The former type usually occurs in summer and the latter in winter.

Kotadia and Ramanathan[61] have studied the behaviour of F_2 region over Ahmedabad under magnetically disturbed conditions in the period from 1953-57. They concluded that the disturbance variation of f_oF_2 showed morning rise and daytime depression. (Fig.1).

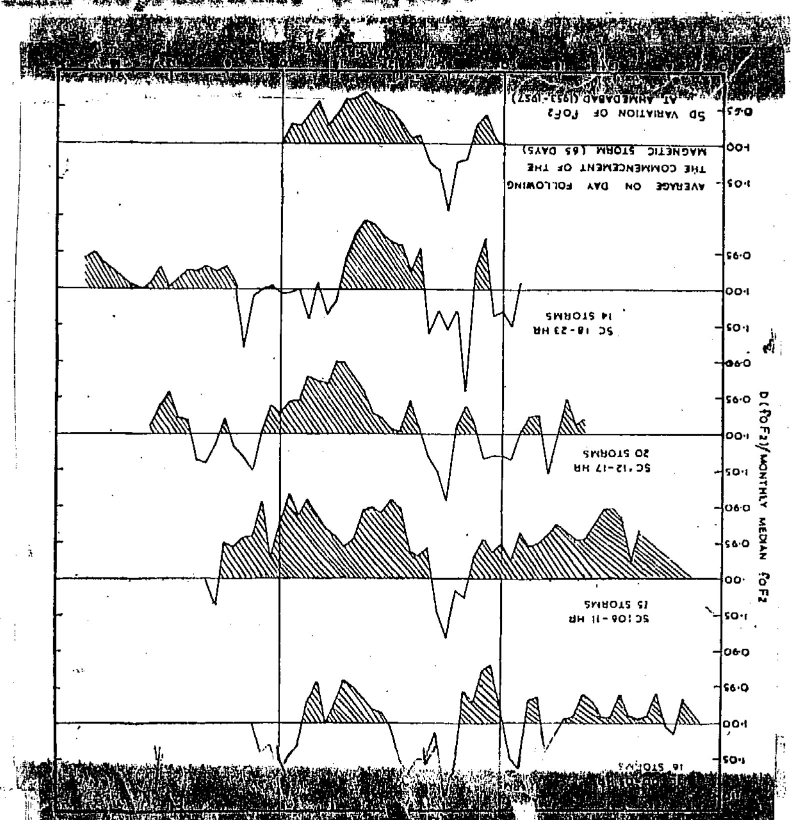

Fig.1. The disturbance variation of f_oF_2 showing morning rise and daytime depression.

Kotadia[62] also examined the relation between spread-F and magnetic activity and conclusively showed that the occurrence of spread-F was less frequent in magnetically disturbed periods (Fig.2).

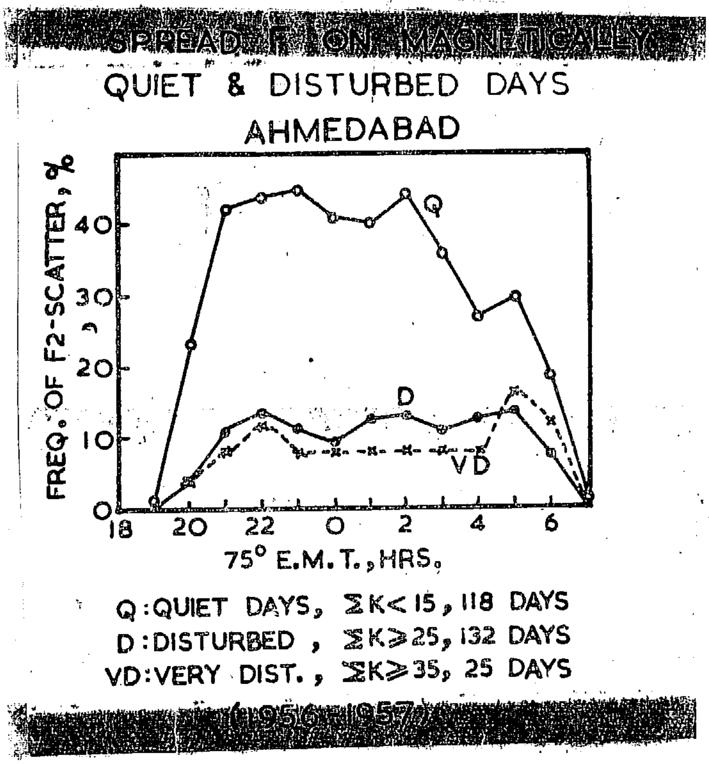

Fig.2. Spread-F on magnetically quiet and disturbed days at Ahmedabad (after K.M.Kotadia).

3 - COMPARATIVE STUDY OF CHANGES IN THE TOTAL COSMIC NOISE ATTENUATION AND CRITICAL FREQUENCY OF THE F_2-REGION ASSOCIATED WITH MAGNETIC STORMS OF SEPTEMBER 2, 1957 AND SEPTEMBER 5, 1957

We have already seen that the total attenuation of cosmic noise on 25 Mc/s at Ahmedabad increases with increase in f_oF_2 for values of f_oF_2 greater than 8 Mc/s. It has also been seen that during night, spread-F is associated with increased attenuation (Bhonsle and Ramanathan[15,16]). During days of magnetic storms, both f_oF_2 and F-scatter are substantially reduced. Large changes also occur in the height of maximum electron density of the F_2-layer.

Cosmic radio noise data on 25 Mc/s in 1957 and 1958 were examined to see in what way the intensity of cosmic radio noise was affected during magnetically disturbed periods. While analysing the day-to-day intensities of cosmic radio noise, it was noticed that on some days, the attenuation was abnormally low for about 2 days in succession and on the third day, the attenuation increased above the normal. This feature was found to be associated with geomagnetic storms. As an illustration of this, in Fig.3, the hourly departures from the normal of cosmic noise absorption on 25 Mc/s, ΔA, in db and Δf_oF_2 are plotted for the two SC type magnetic storms which occurred on September 2, 1957 and September 4, 1957. The first one ended at 00 hr on September 4, 1957 and second one ended at 04 hr on September 6, 1957. Both these storms were severe in intensity. It will be seen that large depressions in the total attenuation were observed on 2 and 3 September 1957 between 12 hr and 23 hr local time. These were accompanied by corresponding decreases in f_oF_2 on the first two days after the commencement of the storm.

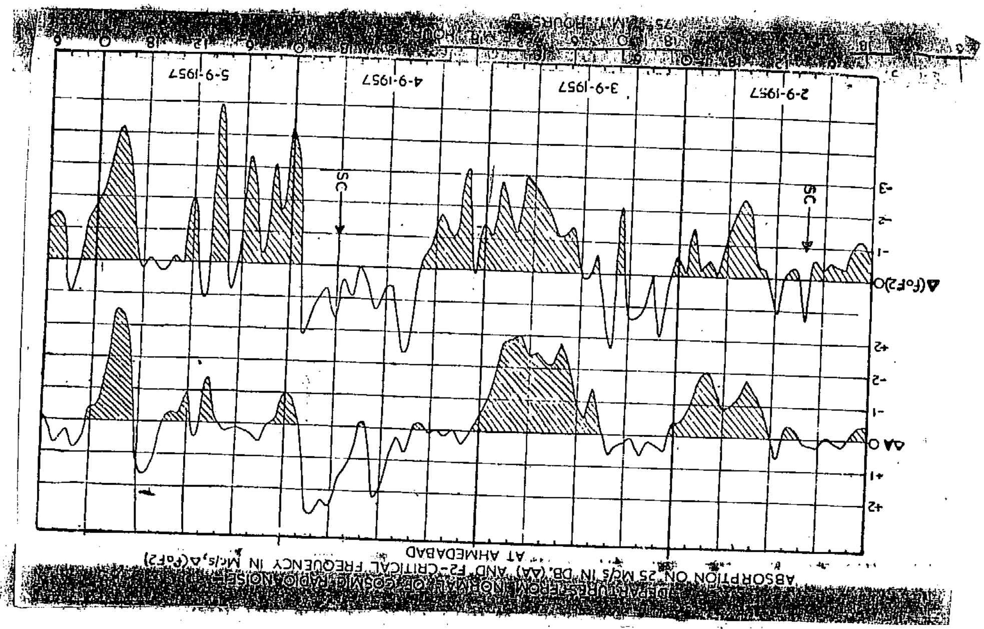

Fig.3. Hourly departures from the normal of cosmic noise absorption on 25 Mc/s in db. and Δf_oF_2.

Each depression in attenuation was associated with decrease in f_oF_2 but the converse was not true. Between 00 hr and 12 hr local time, changes in the attenuation were small. This is understandable because f_oF_2 values are small at these times. But when f_oF_2 values become large, as in the afternoon and the part of the night, there is good correlation between ΔA and Δf_oF_2. On the 4th September, the attenuation was above normal throughout the day. This was associated with abnormally high values of f_oF_2 on that day. Again on the 4th September 1957, another disturbance started at about 1300 hr. On the 5th September 1957, the morning values of ΔA and Δf_oF_2 were not well correlated for the reasons explained above but after sunset large depressions were observed both in attenuation and f_oF_2. Once again it was found that ΔA and Δf_oF_2 were highly correlated between 12 hr and 23 hr local time. As there is a decrease in the amount of F-scatter on disturbed days, this may also be partly responsible for the decrease of absorption at night.

4 - EFFECT OF MAGNETIC STORM ON THE INTENSITY OF COSMIC NOISE

Bhonsle and Ramanathan[17] (reprint enclosed) have analysed cosmic noise intensities on 25 Mc/s at Ahmedabad during 11 magnetic storms all with sudden commencement in 1957 and 1958. It was concluded that during days of magnetic storms, there was, in addition to the usual variation of intensity, namely, attenuations corresponding to a daytime symmetrical part and an asymmetrical component, a further variation. This showed itself as a decrease in the attenuation on the first two days of a magnetic storm and an increase in attenuation on the third day. The decreased attenuation is most clearly seen in the first half of the night on the first and second days after the commencement of the storm and was associated with a decrease in f_oF_2 and F-scatter.

5 - COMPARISON OF DISTURBANCE VARIATION OF f_oF_2 AND THE TOTAL ATTENUATION

The deviation of the total attenuation of cosmic radio noise during a storm from the corresponding monthly mean gives the effect of the magnetic storm on the ionosphere. Fig.4 gives the average hourly values of the departure from normal of cosmic radio noise on the first two days after the commencement of a magnetic storm. It is clear that the effect of the storm is in general to reduce the attenuation throughout the night except between 02 hr to 08 hr local time. After sunrise, the departure of the total attenuation from normal increases till 16 hr local time. After a temporary decrease which lasts till 18 hr, it again increases till 20 hr when it reaches a maximum. It returns to normal by about 2 hr. From 2 to 5 hr, the effect of the storm is negligible. The disturbance diurnal variation of the total attenuation described above may be compared with the disturbance variation of f_oF_2 shown in Fig.1.

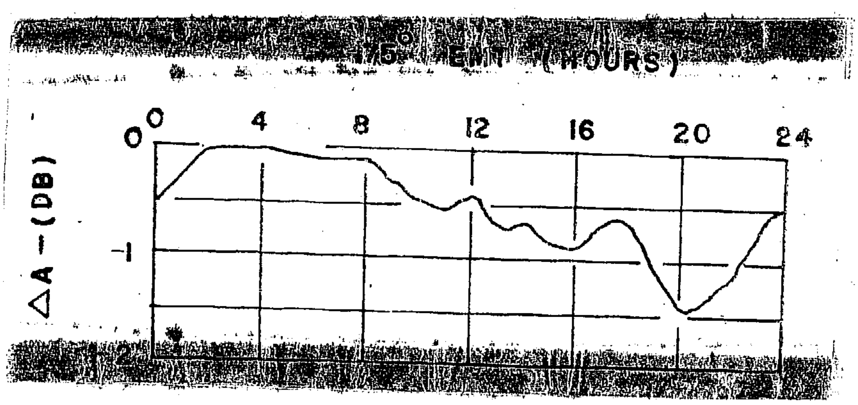

Fig.4. The average hourly values of the departure from normal of cosmic radio noise on the first two days after the commencement of a magnetic storm.

Kotadia and Ramanathan[61] They have analysed 65 storms during the period 1953-57 and studied the effect of the local time of commencement of the storms on the subsequent variations in f_oF_2. The average disturbance variation in f_oF_2 on the day following the commencement is strikingly similar to the average diurnal variation of the departure from normal of cosmic radio noise on the first two days of a magnetic storm.

6. REPRINT : MAGNETIC STORMS AND COSMIC RADIO NOISE ON 25 MC/S AT AHMEDABAD (23°02'N, 72°38'E)

BY BHONSLE, R.V. AND RAMANATHAN, K.R.

Planet. Space Sci. Pergamon Press 1960. Vol. 2, pp. 99–103. Printed in Great Britain.

MAGNETIC STORMS AND COSMIC RADIO NOISE ON 25 Mc/s AT AHMEDABAD (23°02′N; 72°38′E)

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Abstract—Analysing the intensities of cosmic radio noise on 25 Mc/s at Ahmedabad, it was found that during days of magnetic storms there was, in addition to the usual variation of intensity due to the diurnal changes in *D*-region ionisation and *F*-region absorption, a further variation. This showed itself as a decrease in the attenuation on the first two days of the storm and an increase in the attenuation on the third day. The decreased attenuation is most clearly seen in the first half of the night on the first and second days after the commencement of a storm and is associated with a decrease in *F*-scatter.

In a recent paper, Kotadia and Ramanathan[1] have discussed the effects of geomagnetic disturbances on the behaviour of the ionosphere over Ahmedabad. In low latitudes, the *F*2-layer of the ionosphere gets much more disturbed than the lower ionospheric layers. The critical frequency of the *F*2-layer, the height of maximum electron density (h_pF2) and *F*-scatter all undergo significant changes. In auroral latitudes, intense absorption of radio waves below the *E*-region of the atmosphere is usually associated with magnetic storms.

An analysis of the data of cosmic radio noise on 25 Mc/s at Ahmedabad over a period of one year from March 1957 to February 1958 showed that the total ionospheric attenuation suffered by cosmic radio noise could be divided into two components, a *D*-region component and an *F*2-region component. The *D*-region component normally depends on the sun's zenith distance and shows maximum in summer and minimum in winter. The *F*2-region component, when f_0F2 exceeds a certain minimum value, increases rapidly with increasing f_0F2. Ramanathan and Bhonsle[2] have shown that at least in the early part of the night, *F*-scatter is also an important factor which affects night-time attenuation. Since f_0F2 and *F*-scatter change appreciably on magnetically disturbed days, it was felt that an analysis of the data of cosmic radio noise absorption under disturbed ionospheric conditions would give useful information regarding the ionosphere.

The present paper deals with the effect of a few selected magnetic storms on the total attenuation of cosmic radio noise on 25 Mc/s at Ahmedabad. The list of magnetic storms used for this study are given in Table 1.

Table 1

List of Eleven Magnetic Storms all with Sudden Commencement (1957-58)*

Date of beginning	Time of beginning	Date of end	Time of end	Intensity
1957				
3 Aug.	20.58	4	14	m
6 Aug.	10.08	6	20	m
30 Aug.	00.20	31	01	m
2 Sept.	08.15	4	00	s
4 Sept.	18.00	6	04	s
13 Sept.	05.49	13	21	s
21 Sept.	15.06	22	16	s
22 Sept.	18.45	24	02	s
29 Sept.	05.15	30	16	s
26 Nov.	06.52	27	23	ms
1958				
11 Feb.	06.24	12	18	s

*Time in 75° EMT

When making a day to day study of cosmic radio noise, it was found that on some days, the total attenuation had abnormally low values throughout the day and till about mid-night. This often happened for two days in general, a decrease in the attenuation of cosmic radio noise occurred on the first two days of the storm and excess attenuation on the third day.

Fig. 2 shows hourly attenuations of cosmic

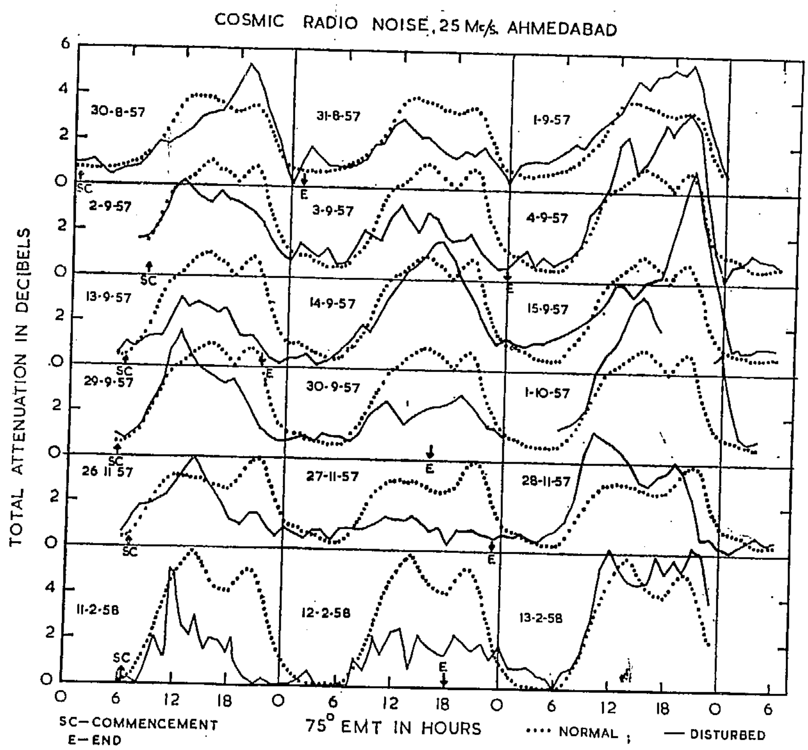

Fig. 1. Hourly attenuation of C.R. noise on 25 Mc/s at Ahmedabad in six magnetically disturbed periods in 1957-58 together with the month's quiet day attenuation for each period. The times of commencement of and end of each magnetic storm are marked in the figure.

succession. On the third day, the attenuation showed a tendency to rise above the normal, after which it returned to normal. It was also found that this feature was associated with magnetic storms. Fig. 1 shows the hourly attenuations of cosmic radio noise on 25 Mc/s at Ahmedabad during six magnetically disturbed periods in 1957–58 superposed on the month's quiet day attenuations for each period. The magnetic storm which occurred on 13 September 1957 was of comparatively short duration and an apparent exception. In radio noise in three periods in 1957 when the magnetic disturbance was more complex and more than one commencement could be identified. Under such conditions, the variation of total attenuation of cosmic radio noise on 25 Mc/s does not follow a fixed pattern.

The deviations of the total attenuation of cosmic radio noise from the corresponding monthly mean gives the effect of a magnetic disturbance on the ionosphere. The usual decrease or increase in the total attenuation of cosmic radio noise associated with changes in

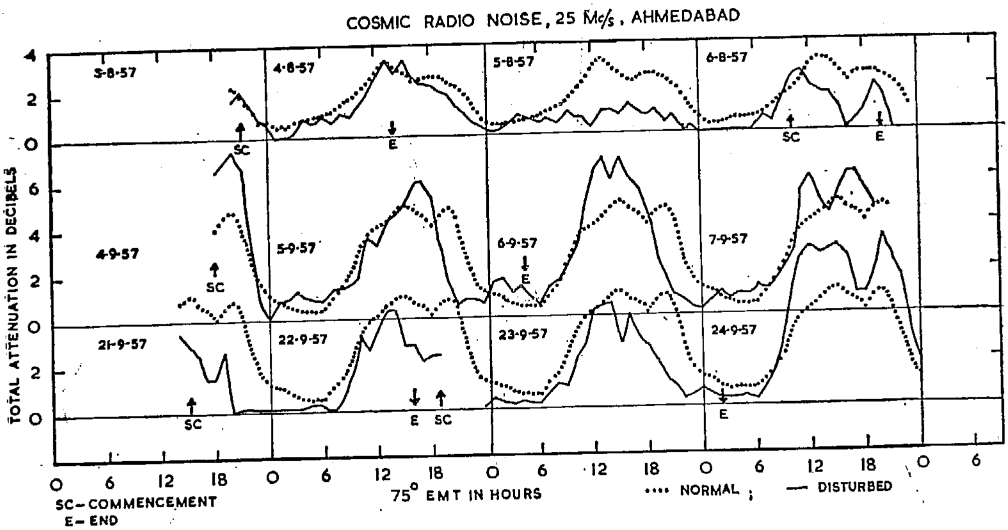

Fig. 2. Hourly attenuation of C.R. noise in three periods in 1957-58 when the magnetic disturbance was complex and more than one commencement could be identified.

f_0F2 when it exceeded a certain value was always noticed. But on magnetically disturbed days there was an additional decrease in attenuation which depended on local time. To determine the average diurnal variation of the change in attenuation due to magnetic storms, the 11 magnetic storms given in Table 1 were analysed. Fig. 3 gives the average hourly values of the departure from normal of cosmic radio noise on the first two days after the commencement of a magnetic storm. It is clear that the effect of a magnetic storm is in

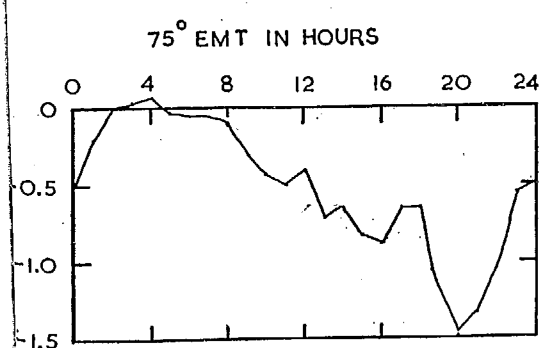

Fig. 3. Average diurnal variation of the departure from normal of C.R. noise on the first two days of a magnetic storm.

general to reduce the attenuation throughout the day except for the period midnight to sunrise. During the later part of the night, low values of f_0F2 are usually observed and the change in f_0F2 has no effect. After sunrise, the departure of the total attenuation from normal goes on increasing till 16 hr local time. After a temporary decrease which lasts till 18 hr, it again increases till 20 hr when it reaches a maximum. It returns to normal by about 2 hr. From 2 to 5 hr the effect of the storm is negligible. The disturbance diurnal variation of the total attenuation of cosmic radio noise described above can be correlated with the results obtained earlier by Kotadia and Ramanathan.[1] They showed that the largest changes in the ionosphere occur on the same day, or the day following the commencement of the magnetic storm. The change at Ahmedabad is a daytime decrease in f_0F2 in contrast to the changes at equatorial stations. The occurrence of spread-F at Ahmedabad is mainly a night-time feature. It was found that during magnetic disturbances, spread-F was generally absent or small, and the usual increase in height and in f_0F2 at 20-21 hr did not occur. It begins usually after 19 hr. In view of the above facts, during daytime, only the changes in f_0F2 are likely to be important in influencing the attenuation of cosmic radio noise. After sunset, however, both the change in f_0F2 and the absence of F-scatter on magnetically disturbed nights would be jointly responsible for the observed rapid decrease in total attenuation.

From the study of the disturbance diurnal variation of the individual storms, it was seen that, in many cases, after the magnetic storm ended, there occurred on the following day an increase in the total attenuation above the normal. Fig. 4 shows the average hourly attenuations of cosmic radio noise associated with magnetic disturbances (mean of five periods). Zero hour has been taken as 0 hr LMT of the day on which the cosmic radio noise attenuation increased above normal at the end of a magnetic storm. For two days before the zero hour, an overall decrease in the total attenuation is observed following the general pattern shown in Fig. 3. On the first day after the zero hour an overall increase in the total attenuation is observed. It is interesting that on this day, the maximum increase in the total attenuation occurs at 20–21 hr. On the two previous nights, at these same times, minimum total attenuation is recorded. This observed overall increase in the total attenuation after the end of a magnetic storm may be partly due to a rise in f_0F2 above normal and partly to a tendency for increased night-time F-scatter. Nothing particular happens on the next two days.

CONCLUSION

The geomagnetic effects on the ionosphere over Ahmedabad are discussed with the aid of cosmic radio noise data on 25 Mc/s. Since $F2$-attenuation depends on the nearness of f_0F2 to the exploring frequency i.e. 25 Mc/s, this method provides a sensitive method of studying the effects of magnetic storms on the $F2$-layer as a whole. The disturbance diurnal variation of the total attenuation of cosmic radio noise shows a dependence on local time. The maximum decrease in total attenuation occurs at about 20 hr local time. An explanation of the observed variation is given in terms of the known variations of f_0F2 and F-scatter on magnetically disturbed days. After the end of the storm, an overall increase in attenuation is observed, which lasts for a day.

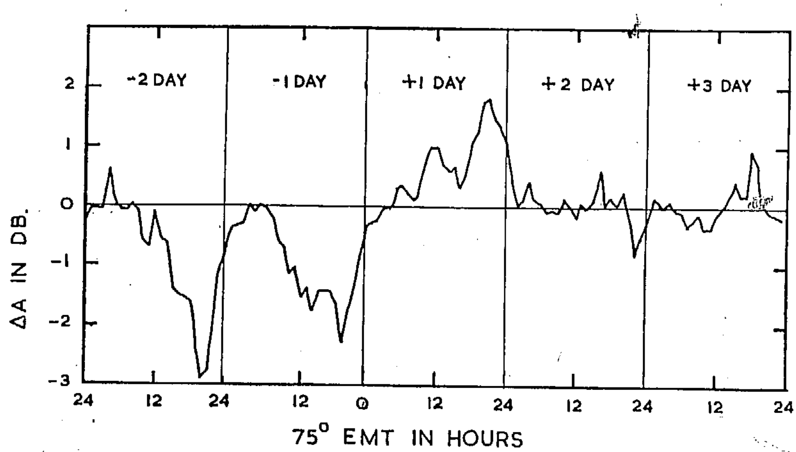

Fig. 4. Departure from normal of hourly attenuations of C.R. noise associated with magnetic disturbances (mean of five periods). Zero hour has been taken as 0 hr LMT of the day on which the C.R. attenuation increased above normal at the end of the magnetic storm. This generally happened two days after the commencement of a simple storm.

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