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**IONOSPHERIC ABSORPTION ON 2.5/2.6 Mc/s AT AHMEDABAD**

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CHAPTER I

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CHAPTER I

IONOSPHERIC ABSORPTION ON 2.5/2.6 MC/S AT AHMEDABAD

INTRODUCTION

Absorption and scattering of electromagnetic waves of different frequencies are two very important properties of the ionosphere, about which our information is still inadequate, and in some regions, even scanty.

In the following, the results of measurements of ionospheric absorption at Ahmedabad using vertical pulsed transmission on 2.5/2.6 Mc/s during the period August 1957 to February 1959 are presented. At the start of IGY, little data were available on the subject, particularly in low latitudes. The earlier work was generally restricted either to noon hours or to a fixed declination of the sun. However, there was a certain amount of theoretical work available and departures from the theoretical conclusions were becoming evident, as also a large latitude variation in ionospheric absorption.

The period of high solar activity during the IGY provided a good opportunity for studying the variation of absorption with the sunspot number. Although the data
collection at Ahmedabad is still inadequate, the work done so far has provided valuable information regarding the diurnal and seasonal variations of absorption in the tropics. By extrapolation, the sub-solar value of the absorption has been derived and this has proved useful in showing up a relation between the sunspot number and the ionospheric absorption for the station.

**Brief historical survey of ionospheric absorption measurements**

The earliest measurements of the absolute magnitude of the attenuation of reflected medium waves dates back to 1928. They were made by the frequency change method by Appleton and Ratcliffe (1930). It was then realised that the main part of the attenuation of high frequency radio waves lies not at the reflecting level but in the region below it.

With the use of pulsed transmission technique, considerable increase in the accuracy of the measurements of absorption came in 1932. The absorption associated with the reflection of radio waves was seen to be largely dependent on the frequency and on the gradient of ionization. The results of diurnal and seasonal variations as also the frequency dependence of absorption were published by White (1934), Best and Ratcliffe (1933), Farmer and Ratcliffe (1935), White and Brown (1936).
The absorption measurements taken since 1935 over a complete solar cycle were summarized by Appleton and Piggott (1954). In addition to the diurnal and seasonal variations, the dependence of absorption on solar activity was noted in their results.

A low layer of ionization, at times capable of total reflection of radio waves was noted by several investigators on many occasions, especially in winter. High power transmitters or sensitive aerial and receiving systems were developed for the purpose. In this connection, the names of Drellinger (1952), Gardner and Pawsey (1953); Gnanalingam and Wees (1954); Gregory (1956) need special mention. Large additional absorption of radio waves was reported from high latitude stations and was identified to be present mostly on days when the lower reflecting layer was observable.

The change in absorption with the change in the directivity of the transmitted signal was investigated by Martin (1935), Beynon (1954), Appleton and Beynon (1955), Alcock (1954) and others. Various formulae were tried out to fit the observed measurements.

Attempts to derive models for the vertical distribution of electrons and their collisional frequencies have been made from time to time both from experimental data and on theoretical grounds. Efforts in these directions by Gardner and Pawsey (1953), Fejer (1955), Mitra (1951), Niclot (1955), and Bates (1956) are noteworthy.
Ionospheric absorption shows considerable variation with latitude as seen from the work of individual groups working at various latitudes. A distinct difference between equatorial and high latitude absorption has been brought out.

Theory of ionospheric absorption

The absorption of electromagnetic waves in the ionosphere is due essentially to the dissipation of the kinetic energy of the electrons, which vibrate under the influence of the radio frequency field, when the electrons collide with other particles or with each other. The heavier ions being less mobile, their direct effect on the propagation would be much less. The rate of loss of energy by electrons would be proportional to

1) the average energy of vibration of the electrons,
2) the number of electron collisions which take place per unit volume per unit time.

The latter would be equal to the product \( N \nu \) where \( N \) is the electron density and \( \nu \) is the collision frequency of the electrons. The absorption data if detailed enough, provide a means of determining the product \( N \nu \).

Now for the propagation of an electromagnetic wave, let us use an absorption coefficient 'k' per unit thickness
of the absorbing medium, \( I \) the amplitude of a wave after traversing a distance \( s \) in the medium, and \( I_0 \), the amplitude which would have been observed if the medium did not absorb. Then

\[
I = I_0 \exp(-ks) \quad \ldots \quad (1)
\]

For the case of a transmitted wave coming back after reflection from the ionosphere we can define a reflection coefficient \( \rho \) to be the ratio of the amplitude of a wave which is reflected once in the ionosphere to the amplitude which would have been received in the absence of dissipative attenuation.

Then

\[
\rho = \exp\left(-k ds\right) \quad \ldots \quad (2)
\]

or

\[
-\log \rho = \int k \, ds \quad \ldots \quad (3)
\]

where the integral is effective for the whole length of the path.

-\( \log \rho \) can now be expressed as the absorption in \( \text{db} \).

The magneto-ionic theory which explains satisfactorily many of the observed ionospheric phenomena (Appleton 1927 and Hartree 1929) shows that, provided the direction of phase propagation is not perpendicular to the magnetic field the absorption coefficient \( k \) for high frequency waves depends on the refractive index \( \mu \), the electron density \( N \), the effective
electron collisional frequency $\nu$ and on the electronic charge and mass $e$ and $m$, according to the equation

$$k = \frac{2e^2}{mc} \cdot \frac{1}{\mu^2} \cdot \frac{N\nu}{\nu^2 + (\omega - \omega_L)^2} \cdots \cdots (4)$$

where $c$ is the velocity of electromagnetic waves in vacuo, $\omega$ the angular frequency of the wave, $\omega_L$ is the angular gyro-frequency corresponding to the earth's magnetic field and the positive and negative signs refer to the ordinary and the extraordinary modes of propagation respectively. At or near a reflection point the direction of propagation of the ordinary wave becomes transverse to the magnetic field, and for this part of the trajectory, the above equation is not applicable.

**Derivative absorption**

If $\nu$ is large compared to $\omega_L$, the influence of the earth's magnetic field may be neglected; also if $\nu < \omega$, the absorption coefficient may be written as

$$k = \frac{2\pi e^2}{mc} \cdot \frac{1}{\mu^2} \cdot \frac{N\nu}{\omega^2} \cdots \cdots \cdots (5)$$

subject to the same assumptions.
\[ \mu^2 = 1 - \frac{4 \pi Ne^2}{m c^2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6) \]

then
\[ k = \frac{\sqrt{x}}{2e} \left( \frac{1}{\mu} - \mu \right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7) \]

If the above simplifying assumptions are not made, then the absorption index can approximately be expressed as
\[ k = \frac{\sqrt{x}}{2e} H \left( \frac{1}{\mu} - \mu \right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3) \]

where \( H \) is a numerical factor depending on the ratio \( \omega / \nu \), the angle between the wave direction and the magnetic field and the magneto-ionic component concerned.

The absorption index and hence the total absorption will depend critically on the value of the refractive index. This type of absorption is termed deviative absorption since the deviation of a single ray is also governed by the value of the refractive index.

**Non-deviative absorption**

When \( \mu \) is approximately equal to unity, equation (4) can be written as
\[ k = \frac{2 \pi e^2}{mc} \frac{\frac{N}{\nu}}{\nu^2 + (\omega - \omega_L)^2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (9) \]
When the direction of propagation of the radio-wave is not changed during transmission through an ionized medium, it is customary to term this type of absorption as non-deviative.

For cases such that \( \nu^2 \ll (\omega + \omega_L)^2 \) the total non-deviative absorption may be written as

\[
\int k ds = \frac{2\pi e^2}{mc} \frac{1}{(\omega + \omega_L)^2} \int N \nu ds \quad \text{(10)}
\]

The above expressions apply to the so-called "quasi-longitudinal" (q.L.) propagation. The transition from q.L. to q.T. (quasi-transverse) types of propagation depends on the value of the collisional frequency at the level at which the absorption is considered to take place.

Appleton (1937) has shown that for an absorbing region of the Chapman type, the non-deviative absorption is given by

\[
\int k ds = \int 2\pi \exp \frac{4\pi e^2}{mc} (\cos \chi)^3/2 \frac{N \nu o H}{(\omega + \omega_L)^2} \quad \text{(11)}
\]

where \( N_0 \) is the maximum electron concentration at noon when the sun's zenith distance is zero. \( H \) is the scale height of the atmosphere in which the layer is formed, and \( \nu_0 \) is the electron collisional frequency at the height of maximum ionization of the layer \( h_m \) at noon for \( \chi = 0 \).
Besides the assumption of a Chapman layer, it is assumed that $V$ varies as

$$V = V_0 e^{-z} \quad \ldots \ldots \ldots \ldots \ldots (12)$$

where $z$ is the height measured from $h_m$ in terms of the scale height. Further it is assumed that $\alpha$, the coefficient of recombination is constant throughout the layer and that $V$ is small compared to $\omega$.

It would be seen that from equation (11) that for the assumptions made, the integrated non-deviative absorption for up and down path in the ionosphere would be proportional to the $3/2$ power of the cosine of the solar zenith angle and inversely to the square of the frequency.

Determination of the reflection coefficient

The reflection coefficient $\rho$ can be estimated by comparing the amplitude of a direct wave from a transmitter with that of the reflected downcoming wave as received near the ground.

Let $F'$ - the amplitude of the once reflected downcoming wave at the receiver

$$d = \text{the distance travelled by the downcoming wave in a single up and down journey.}$$

Then $F' = \frac{B \rho}{d} \quad \ldots \ldots \ldots \ldots \ldots (13)$
where $B$ is a constant dependent on the amplitude of the wave sent upwards by the transmitter.

If $Q$ is the amplitude of the direct wave at the receiver, we can write

$$Q = A/d_0 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (14)$$

where $A$ depends upon the amplitude of the direct wave sent by the transmitter and its attenuation by the ground and $d_0$ is the distance travelled by the wave over the direct path.

Then we get

$$\frac{F'}{G} = \frac{B \cdot d_0}{A \cdot d} \cdot \rho \quad \ldots \quad \ldots \quad (15)$$

or

$$\rho = \frac{A}{B \cdot d_0} \cdot d \cdot \frac{F'}{G} = C \cdot d \cdot \frac{F'}{G} \quad \ldots \quad (16)$$

where $C$ is a constant and may be called 'the transmission coefficient'. It is related to the characteristics of the transmitting aerial, the ground attenuation and the distance between the transmitter and the receiver.

Let $F'' = $ the amplitude of the twice reflected echo and $\rho_g$ - the reflection coefficient of the ground

then we have

$$F'' = \frac{B \cdot \rho^2 \cdot \rho_g}{2 \cdot d} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (17)$$
If to a first approximation \( P_g \) may be assumed equal to unity we may write

\[
F^o = \frac{3 \rho^2}{2d} \quad \ldots \ldots \ldots \quad (13)
\]

Then \( \rho = \frac{F^o}{F^1} \quad \ldots \ldots \ldots \quad (19) \)

and \( C = \frac{2 \rho^2 G}{(F^1)^2d} \quad \ldots \ldots \ldots \quad (20) \)

Thus the transmission coefficient \( C \) could be evaluated when more than one echo is present and in addition to the amplitudes of the first and second echoes we measure the amplitude of the ground pulse as also the height of the reflecting layer.

Generally instead of \( C \), the quantity \( 20 \log C \) is tabulated in db. With the measurements at Ahmedabad the value of \( 20 \log C \) was evaluated on more than two dozen occasions and the average worked out to be 17 \( \pm \) 0.4 db. During day-time, generally only the first echo was recordable and the calculation of \( \rho \) was made by using equation (16).

Methods of ionospheric absorption measurement

A) Constant output technique

At Ahmedabad a constant output technique was employed
for the absorption measurements. A pulsed r.f. transmitter with a stable output was used to radiate essentially in the vertical direction. The received echo signal was fed to a sensitive receiver through a variable attenuator which was adjusted to give a constant amplified output. Owing to fluctuations, a large number of readings of the attenuator had to be taken in order to obtain a reasonable mean value of the attenuation at a given time. The reasons for the setting in of non-dissipative phenomena and measures taken to combat their effects are discussed later.

The system using the constant amplitude of the output signal had the advantage that no stage of the receiver is saturated during measurements. The construction and other details of the equipment are described later. A brief mention of other systems normally in use for absorption measurements is made below.

B) Constant gain technique

An alternate method would have been to keep the gain of the receiver constant, thus allowing the output to vary as the input signal changes in intensity. Usually very large variations of signal strength are encountered during the course of absorption measurements and a dynamic range of the receiver becomes essential, over which the output has to remain proportional to the input.
Usually receivers with quasi-logarithmic responses are usable for large coverage of signal variations, but are suitable for automatic recording of absorption measurements.

C) Technique using $F_{\text{min}}$

The minimum frequency recorded in sweep frequency ionosonde $P'$ records is related to the attenuation of the radio waves and could be used as an index of absorption. This however is a function of other variables also such as receiver and transmitter frequency responses. Since these may have to be frequently readjusted for proper functioning of the equipment, direct computation of attenuation by using this index is rendered difficult.

D) Absorption measurements using extraterrestrial sources

Following the discovery of galactic noise by Jansky (1932) and the galactic survey by Grote Reber (1940), Hey, Parson and Phillips (1943) and Bolton and Stanley (1943) detected the existence of discrete sources of cosmic radio noise. The attenuation of cosmic noise as it passes through the ionosphere was measured by Mitra and Shain (1953). In this method, the choice of frequency is restricted to values larger than the critical frequencies of the upper regions of the ionosphere and is not particularly suitable for the study.
of the lower regions of the ionosphere except during sudden ionosphere disturbances. The method is finding increasing use for studying ionospheric attenuation.

The constant output technique adopted at Ahmedabad though laborious, as requiring constant manipulation of the attenuator, has proved to be extremely stable throughout the course of observation and has given fairly useful data.

The experimental set up at Ahmedabad

The receiving and transmitting systems which were constructed by the author for the measurement of ionospheric absorption were separated by about half a mile from each other. This was to avoid the induction field of the transmitter as also certain disturbances originating near the laboratory. A description of the set-up is given in the following:

a) Transmitting system

The transmitter had a peak power of about 1 K.W. with a pulse repetition frequency of 50 C/sec. The pulse-width was controllable in steps and could be increased up to 330 /μ sec.

The block diagram of the transmitter is shown in Fig.11. The output stage was used in push pull so as to give sufficient power. The availability of material including valves and components was one of the basic considerations in
designing the transmitter. Most of the transformers, chokes etc. had to be designed and manufactured at the laboratory.

The circuits of some of the stages are shown in Fig.1.1. Time delays were utilised for putting on different circuits in a sequence and could be operated by remote control with a single switch.

An inverted V type antenna was erected with a tower 55 ft. in height. The base of the V was 90 ft. and was fed from a 600-Ω twin wire transmission line. The antenna was terminated with a 600-Ω resistance. The output stage of the transmitter was coupled to the transmission line through a coil, coaxial to the tank circuit of the final power stage. Two P-123A power triodes were connected in push pull as the r.f. amplifiers. The modulated oscillator was made up of two 307 tubes in push pull, which remained normally in cutoff except during the gated pulse-interval. The pulse width could be controlled externally by adjusting the time constant of a gate pulse fed from a modulator stage consisting of two 6L6 tubes.

The initial triggering pulse for the modulator by using a square wave was generated from the mains sinusoidal voltage and the phase of the square wave, with respect to the mains voltage, could be adjusted by varying a resistance in a resistance-condenser combination. The 50 c/s pulse repetition frequency of the pulse generator was thus derived from the mains voltage.
Both the output and the oscillator stages of the transmitter were tunable by means of variable condensers. This could give a fairly stable output on a wide range of frequencies.

Fig. 1.3 shows the photograph of the transmitting equipment. The necessary power supplies were constructed and situated in the lowest chassis of the equipment. The largest power supply was 2500 Volts D.C. and was capable of giving one ampere of current for the final power amplifier stage.

Provision was made for testing out individual units. Separate switches for putting on filaments and high tension were provided. The oscillator and power amplifier tank circuits were situated in the topmost chassis and could be easily tuned for a given frequency. Check points were incorporated at each significant position for quick checking. Panel meters indicated readily any failure.

Power was fed to various units through a one K.W. constant voltage transformer. This was to take care of the normal fluctuations of the mains voltage. A motor showing the r.f. power was incorporated in the final stage of the transmitter. Routine checks of various meter readings were taken to maintain a stable output. Variations which occurred in spite of these precautions, were taken care of by noting
Fig. 1.3 Photograph showing part of transmitting equipment
the strength of the ground pulse at the receiving end, both at the start and finish of each set of observations lasting over a few minutes.

Fig.1.1 shows the sequence of switching operations. The filaments of the mercury vapour rectifier used in the 2500 volts and 1000 volts power supplies required heating prior to the switching on of the high tension. A thermal delay switch was used to feed the high tension, 30 seconds after the filament circuit was on. The transmitter could be put on or off by a remote switch connected in parallel with the main switch. For the sake of safety, arrangement was made to render the remote switch inoperative while monitoring the equipment locally.

b) Receiving equipment

At the receiving site a simple inverted L type of antenna mounted at a height of 45 feet was found to give satisfactory results. The antenna was fed to a 120 db attenuator which could be adjusted in steps of decades, units or fractions of a db. The fractional dial was rarely usable.

The attenuator output was matched to the first R.F. stage of the receiver. A communications type receiver was suitably modified for the pulsed reception. It had two R.F.
CIRCUIT DIAGRAM OF TRANSMITTER

FIG 1.1
and two I.F. stages with a separate oscillator and a mixer. The receiver was found to give extremely stable performance throughout the course of the observations. The following were some of the measures taken to widen the band width of the receiver in order to reproduce the square wave shape of the input signal.

1) Flat tuning of the I.F. amplifier.

2) A low load impedance for the second detector, connected between the cathode and ground.

3) Construction of a video stage following the detector, the output from this being fed to the plate of the display tube.


The output was displayed on an A-scope built by the author. A circuit diagram showing some of the features of the same is shown in Fig. 1.2. The time-base was generated by using a thyratron gas discharge tube. A voltage derived from the mains was used for triggering the same. A phase shifting network was introduced in order to displace the ground pulse and the echo signal conveniently on the face of the cathode ray tube. A tube with 5" diameter was found to be suitable. Normally the gain of the video stage was so adjusted as to keep the amplitude of the unattenuated ground pulse to be 4" on the tube. This was therefore the saturation level
of the video stage. Another line situated 2" above the

time-base level was permanently marked on the face of the
tube. This served as the reference level to which the echo
amplitude was adjusted before taking the attenuator reading.

In case any replacement of the cathode ray tube
become necessary care was taken to choose another with
similar characteristics. At times as many as ten tubes were
tried before the appropriate one was located. Any change in
the over all sensitivity of the equipment was taken care of
by appropriate controls from time to time.

The D.C. supply for the receiver was electronically
regulated by using a conventional stabilized circuit
(Gilmore and Sands). For further gain stability the filaments
were fed from a constant voltage transformer. The oscilloscope
was fed from two built in supplies one giving 1200 volts D.C.
and another 300 volts D.C. Conventional controls such as X
and Y shifts as also the Focus and intensity controls were
incorporated in the design of the oscilloscope. Here again
the power was fed-through a constant voltage transformer.

For measurement of height of the echo from the start
of the ground pulse a 3 kc/s multivibrator was built in. The
output from the same was differentiated, amplified and fed
to one of the X plates of the oscilloscope, thus providing
50 km height marks on the time base itself. The direction
I
of the height markers was such that they appear as small, sharp spikes pointing downward. Since the 3 ke/s oscillator was not crystal controlled the heights of echo pulses were compared with ionosonde records taken at the same place. In general good frequency stability was observed for the height markers.

Non-dissipative phenomena and the absorption measurements

There are many non-dissipative phenomena which alter the amplitude of the echo signal completely from that expected from pure dissipative causes. The effects due to these have to be recognized and need to be corrected if meaningful results have to be deduced. Some of the main non-dissipative effects and the measures that were taken to combat the same are discussed in the following:

I. Fading

Three different types of fadings are generally encountered during the absorption measurements: a short period fading, a long period fading and magneto ionic fading. Considering each one separately:

a) short period fading

The short period fading has generally a period of a few seconds and is caused by the irregularities in the
ionosphere. Due to these the amplitude of a radio wave received on the ground varies as if modified by a large number of random perturbations. Ratcliffe (1943) has shown that the resultant amplitude fluctuations could be represented by a Rayleigh distribution and the mean amplitude of a wave fading according to the above distribution is larger by a factor of 1.3 from the mean amplitude of a steady signal having the same mean power.

More frequently the amplitude fluctuations are more accurately represented by the superposition of a coherent specular reflection and the random fluctuations. This model gives a distribution of amplitude more like a Gaussian distribution, for which the mean, median and mode amplitudes are all practically equal to the Root mean square value.

Now it is usual to assume that the average energy in a fading signal is equal to the average energy of a steady specularly reflected signal which would have been obtained if the fading was absent. Thus the root mean square (R.M.S.) amplitude should be independent of the amount and type of fading. Hence the R.M.S. value should be the most reliable for absorption purposes. In practice however it is inconvenient to measure R.M.S. value.

It would thus be seen that for a shallow fading the median value is close to the R.M.S. value whereas during deep
fading the distribution is Rayleigh type and the R.M.S. value differs largely from the mean or median value.

At Ahmedabad a large number of readings of the echo signal were taken spaced by ten second interval. The median value was then utilised for the computation of the absorption coefficient. Large sequences of observations were at times required to make the readings statistically significant.

Usually the higher orders of reflection are most incoherent whereas Piggott (1953) has shown that the degree of incoherency of the first order echo varies diurnally with a maximum at night, thus decreasing the amplitude of the first order reflection during day by a factor of 1.3 without seriously affecting the higher order reflections. Due to this reason the transmission constant deduced at night would be smaller by 1.6 times, introducing maximum error of 3 db in the attenuation.

At Ahmedabad the instrument's constant was derived as far as possible in the early evening hours and especially when the fading observed was minimum. Moreover two dozen sets of observations spread over a number of days were taken in computing the constant. The error if at all due to the variations in in-coherency of the first order echo is therefore expected to be very much reduced.
b) Long period fading

The period for this type of fading is generally exceeding five minutes and it is believed to be associated with curvature in isodense electron contours. Efforts were made, whenever possible to detect this type of fading, to continue the observations to cover a complete cycle of variation.

c) Magneto iono fading

Any wave with arbitrary polarization would exhibit two characteristic modes, the ordinary and the extraordinary, when incident on the lower boundary of the ionosphere. The two may interfere to give a fading of the received echo.

The two modes have different time delays as they reach the receiver. The choice of pulsed transmission such as used at Ahmedabad permits the separation of the two modes to a considerable extent by selecting the proper bandwidth of the transmitted pulse.

The absorption measurements at Ahmedabad were restricted to the ordinary component. This was absorbed considerably less than the extraordinary, especially during day time and could be picked up on the oscilloscope readily. Moreover the combined amplitude of one week and one strong component has been reported by earlier workers to be equal to...
the mean amplitude of the stronger component even though
the type of fading is now altered.

In addition to the various types of fadings discussed
above there are other non-dissipative phenomena which have
to be taken care of such as:

II. Spatial attenuation

Normally, Breit and Tuve's theorem shows that the
amplitude of a wave will vary inversely with the apparent
height of reflection. In the presence of a magnetic field
the theorem is not strictly applicable. The error however
would not be appreciable for frequencies well away from the
critical frequencies. In the present analysis, observations
which were likely to be influenced by the E layer critical
frequency were excluded while calculating the absorption
index for the non-dissipative region.

III. Ionospheric dispersion

The square wave envelope of the pulsed transmission
generally gets distorted due to the variation of the phase
path with frequency in the ionosphere. This brings in errors
in amplitude measurements of the echo signals. The transmitter
and receiver may bring in further distortion in the pulse shape
In the present study by proper choice of the receiver and transmitter band widths, the latter effect was taken care of. As for the ionospheric dispersion it was observed that for a given echo signal the received pulse shape was more faithfully reproduced if the pulse width of the transmitter was increased up to an optimum value beyond which no further change was noticeable. Thus by proper choice of the pulsewidth the dispersion effects could be reduced; however, with larger pulse widths, the selection of magnetoionic components was made difficult and a compromise between the two aspects had to be resorted to.

IV. Scattered reflections

Scattered reflections believed to be due to abnormally dense clouds of ionization were at times noticeable during measurements. The received wave shape was very variable and spread out.

Measurements during such events were purposefully excluded from the analysis, more particularly when the equipment was being calibrated.

Results of analysis and discussion

The method of taking the observations and the
precautions taken there in have already been discussed above. The results of the observations from Aug. 1957 to July 1958 were reported in the Journal of the Institution of Telecommunication Engineers, 1959. The frequency had to be altered slightly during May 1959 and the observations were continued up to February 1959. The results of the measurements were further summarized and presented during a symposium arranged by the Indian Council of IGY. The two reports are included in the following: -
MEASUREMENT OF THE IONOSPHERIC ABSORPTION
ON 2-5 MC./S. AT AHMEDABAD

J. S. SHIRKE*

Abstract

Measurements of ionospheric absorption were carried out at Ahmedabad (latitude 23°0'N., longitude 72°6'E.) on 2-5 mc./s., using vertical pulsed transmission during the period August 1957 to July 1958. The strength of the transmitted signal was kept constant and the intensities of the vertically reflected pulses were cut down by the use of a passive attenuator so as to give a constant intensity of signal on the oscilloscope screen of the receiving circuit.

It was found that the mean monthly values of the absorption plotted against cos X for each month from August 1957 to July 1958 obeyed a relation of the type log p oc cosnX. The value of 'n' for individual months ranges from 0.64 to 0.89 and the mean value is 0.73. To eliminate the effects of the seasonal changes in the noon zenith distance of the sun, the values of absorption for cos X = 1 were obtained by extrapolation. These extrapolated values show a fairly close correlation with the sunspot number.

Generally the maximum absorption is reached some time after the local noon, suggesting relaxation time for the D region. Absorption larger than that expected by the cos X law is observed in the late evening hours. This is attributed to a contribution from the deviative type of attenuation in the E layer.

The evaluation of ionospheric absorption by measuring the intensities of reflected pulses of radio waves of frequency 2-5 mc./s. was started at Ahmedabad in 1957 and regular observations have been made from July 1957. The pulsed transmitter was built in the Physical Research Laboratory. It has a peak power of about 1 kW. and pulse repetition frequency of 50 c./sec. The receiving equipment is installed at a distance of about half a mile from the transmitting site. This cuts down the inductive field of the transmitter and also reduces other disturbances originating in the laboratory.

A constant output technique as suggested by the I.G.Y. Committee was adopted for the measurements. The input from the receiving aerial is fed through a passive attenuator to a communication type receiver suitably modified for pulsed reception. The output of the receiver after detection is displayed on the screen of a cathode ray oscillograph. Good stability is maintained by utilizing stabilized power supply and by keeping the gain of the receiver unaltered. The attenuator dials are adjusted to maintain a constant output of echo signal on the screen of the oscilloscope. In order to minimize the effects of fading a number of readings (once every 10 sec.) are taken to cover a fading cycle. The median values are then utilized to compute the attenuation. Any alteration in the power of the transmitter is allowed for by noting the readings of the ground pulse at the receiving end. Height markers derived from a 3 kc./s. multivibrator synchronized with the mains are included in the time-base itself. This allows the measurement of the apparent height (h) of the reflecting layer. The attenuation is calculated by using the usual formula:

$$\rho = \frac{F' \times d}{G} = \frac{2F'G}{F''}$$

where $\rho$ = the reflection coefficient for vertical incidence,

$F'$ = the amplitude of the once reflected downcoming wave at the receiver,

$F''$ = the amplitude of the twice reflected echo,

$G$ = the amplitude of the direct wave at the receiver,

$d$ = the actual distance travelled by the downcoming wave in a single up and down journey.
C = a constant involving the transmission characteristics of the transmitting aerial, the ground attenuation and the distance between the transmitter and the receiver.

The value of C is computed from time to time from the knowledge of $F'$, $F''$, $G$ and $d$, when more than one echo are present. This necessitates observations on suitable occasions, usually during night. Two dozen sets of observations were made during the period noted above to determine the C values used.

$-\log_{10} \rho$ gives the value of attenuation in nepers, which can be converted to decibels. The absorption in decibels is denoted by $L$.

Hourly observations are made during sunlit hours on many days in a month. The mean for each hour is then found from as many readings as possible for each month. Table I shows the values of mean hourly absorption for different months during the period August 1957 to July 1958.

In Fig. 1 are plotted the monthly mean values of absorption at different times of the day for different months.

Fig. 1 — Mean daily variation of absorption on 2.5 Mc/s. for different months
**TABLE I**

<table>
<thead>
<tr>
<th>Month</th>
<th>T</th>
<th>L</th>
<th>T</th>
<th>L</th>
<th>T</th>
<th>L</th>
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T — 75° E.M. time, L — absorption in db.

**TABLE II**

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<td>46</td>
<td>0.69</td>
<td>48</td>
<td>0.72</td>
<td>46</td>
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SHIRKE: MEASUREMENT OF THE IONOSPHERIC ABSORPTION ON 2.5 MC/S.
Large diurnal as well as seasonal variations are noticed. The maximum noon absorption can be read off from the curves. To bring out the dependence of the absorption on the hour angle, the values of \( \cos X \) on the 15th of each month were plotted against the absorption \( -\log p \) on logarithmic paper.

Sample plots are shown in Fig. 2 for different months. The \( \cos X \) values with corresponding absorption values are shown in Table II. The points lie fairly closely on straight lines, especially for higher values of \( \cos X \). This brings out that the nature of the relation is of the type \( \log p = \cos X^n \).

The index \( n \) can be obtained from the slope of the line for each month. Table III shows the slopes for different months, as also the maximum absorption \( L_{\text{max}} \) as read off from the diurnal curves of Fig. 1.

In order to obtain the values of absorption that would have been observed for \( \cos X = 1 \), the lines of \( L \) against \( \cos X \) are extended to \( \cos X = 1 \) as shown in Fig. 2. These extrapolated values corresponding to \( \cos X = 1 \) are denoted by \( L' \) in Table III.

The variations of \( L \) and \( L' \) for different months are shown in Fig. 3. The mean monthly sunspot number \( R \) as observed at KodaiKanal Observatory has been plotted on the same graph.

It is interesting to note the similarity in the trends of the curves \( L' \) and \( R \).

### Table III

<table>
<thead>
<tr>
<th>Month</th>
<th>Maximum Absorption (Noon)</th>
<th>Extrapolated Absorption for ( \cos X = 1 )</th>
<th>Kodai-Kanal Sunspot Number</th>
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<tr>
<td>Jan.</td>
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<td>May</td>
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</tr>
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<td>June</td>
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<td>59</td>
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<tr>
<td>July</td>
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</table>

**Fig. 2 — Monthly Mean Values of Absorption on 2.5 mc./m. Against \( \cos X \) for Different Months (Plotted on Logarithmic Scale)**
SHIRKE MEASUREMENT OF THE IONOSPHERIC ABSORPTION ON 2-5 MC./S.


Fig. 3 — Observed noon absorption L on 2.5 mc./s., extrapolated absorption L' for cos X=1 and relative sunspot number.

Results

Dependence of log P on solar activity — It is observed that there exists a positive correlation between the sunspot number and the absorption of 2-5 mc./s. waves reflected from the ionosphere.

The values of absorption for different months corrected for seasonal variation by extrapolating to cos X = 1 have been plotted against the sunspot number. The points fall on a straight line for most of the months. May, June and July 1958 show less absorption than expected. The equation of the straight line is seen to be

\[ | \log P | = 47 (1 + 0.002 R) \]

where \( | \log P | \) is expressed in decibels.

Diurnal Variation of Absorption

A law of the type \( \log P \propto \cos^n X \) is found to hold for the diurnal variation of absorption throughout the year. The value of the index \( n \) for different months varies from 0.64 to 0.89. The mean value of \( n \) for the year is 0.73.

It is observed that during the periods of increased solar activity, the line corresponding to \( \log \cos X \propto \log | -\log P | \) shifts bodily, maintaining a slope which varies only slightly about the mean value of \( n=0.73 \). This indicates that if the absorption values are corrected for the changing solar activity, the value of \( n \) as derived from the seasonal changes of the noon zenith distance would be of the same order as that observed from the diurnal changes of the solar zenith distance.

The critical frequency of the E layer is about 4-3 mc./s. at noon at Ahmedabad during the summer months and about 4.0 mc./s. in winter. The working frequency of 2.5 mc./s. is therefore sufficiently far from the noon foE so as to be little affected by the deviative absorption in the E layer when the sun is high.

The relationship \( \log P \propto \cos^n X \) does not appear to hold for low values of \( \cos X \); generally a larger absorption is observed round about 1700 hrs. Now foE at 1700 hrs. falls below 3-0 mc./s. at Ahmedabad especially during winter months and the additional attenuation might be due to the fact that the deviative type of absorption sets in owing to the closeness of the exploring frequency to foE.

It can be seen from the diurnal curves for most of the months that the afternoon absorption for a given value of \( \cos X \) is slightly larger than the forenoon absorption for the same \( \cos X \).
This suggests some relaxation time for the D region, where most of the absorption takes place during noon hours.

Comparison of Results Obtained Elsewhere

Appleton and Piggott working with a long sequence of observations at Slough have shown that both the diurnal as well as the seasonal values of absorption follow a law of the type \( \log p \propto \cos \chi \) when we correct the values of the absorption for the changing solar activity. The value of the index \( n \) is found to be about 0.75 both for seasonal as well as diurnal variations. The mean value of 0.73 observed here for \( n \) agrees well with this result. A similar value for seasonal changes in noon \( \cos \chi \) is also in agreement with their results.

From observations extending over a complete solar cycle Appleton and Piggott have shown that the relation between the sunspot number and the observed absorption is linear and is given by \( -\log p = a (1 + bR) \). A similar dependence of absorption on the sunspot number has been observed here. However, the slope of the line as given by \( (ab) \) is smaller than that observed at Slough. Calculations based on Slough results lead to very high values of absorption during large sunspot activity.

The values of \( n \) as noted by other observers are as follows:

- Taylor working on continuous waves of frequency 2.061 mc./s. has shown the value of the index \( n \) to be 1.00 in summer, 0.87 in equinox and 0.73 in winter.
- From diurnal measurements at Ibadan, Skinner and Wright reported a mean value of \( n=0.7 \). A similar value has been obtained for the equatorial station of Singapore. However, a very high value of \( n=2 \) has been obtained for these stations from the seasonal data, which is difficult to explain.

For the auroral zone, Davies and Hagg have found the value of \( n \) to be 0.5.

In India, Mitra and Mazumdar working on 5.0 mc./s. reported a mean value of \( n=0.62 \) from considerations of the diurnal variation of intensity with changing solar zenith distance.

Acknowledgements

Ionospheric studies at Ahmedabad are receiving financial support from the Council of Scientific & Industrial Research, India. The author is indebted to Prof. K. R. Ramanathan for guidance. Thanks are due to Sri R. Sethuraman, to Sri S. K. Alurkar, to Sri C. M. Patel and to other colleagues without whose help transmissions at regular intervals would have been difficult.

References

Presented at the symposium held in Delhi by the Indian National Committee for the IGY

IONOSPHERIC ABSORPTION ON 2.5/2.6 Mc/s AT AHMEDABAD

J. S. SHIRKE*

Summary

Measurements of ionospheric absorption using vertical pulsed transmission were carried out at Ahmedabad (lat. 23°00' N, long. 72°36' E) on 2.5 Mc/s from August 1957 to April 1958 and on 2.6 Mc/s from May 1958 to February 1959.

The mean monthly values of absorption $L$ obeyed a relation $L \propto \cos^n \chi$ where $\chi$ is the zenith angle of the sun. The mean value of $n$ is found to be 0.70 for 2.5 Mc/s and 0.30 for 2.6 Mc/s. The average for the whole period being 0.75. The value of $n$ was 0.36 for summer, 0.63 for winter and 0.74 for the equinoxes.

For removing the seasonal variations, the values of absorption were extrapolated to $\cos \chi = 1$. These extrapolated values showed a linear dependence on the sunspot number $R$. It was observed that $L' = L_0 (1 + \beta R)$ where $L_0 = 47$ db and $\beta = 0.0020$ for 2.5 Mc/s and $L_0 = 45$ db $\beta = 0.0018$ for 2.6 Mc/s.

*Physical Research Laboratory, Ahmedabad 9, INDIA.
Measurement of ionospheric absorption was carried out at Ahmedabad (Lat. 23°0' N, Long. 72°6' E) during the period August 1957 to February 1959 by measuring the intensities of vertical pulse reflections. The frequencies used were 2.5 Mc/s from August 1957 to April 1958 and 3.6 Mc/s later. The change was made in order to reduce the interference from the harmonics of the local broadcasting station. Vertical pulsed transmission was used in both the cases. The method of taking the measurements and some of the results obtained till July 1958 have been published in the Journal of the Institution of Telecommunication Engineers. The additional data for the period July 1958 to February 1959 have now been analysed. The results obtained confirm the earlier results.

It was shown in the previous paper that the monthly mean values of absorption obeyed a relation of the type
\[
-\log \rho \propto \cos^n \chi
\]
where \( \chi \) is the zenith angle of the sun and \( -\log \rho \) the absorption in db and \( n \) an approximate constant.

A similar law is found to hold for each of the remaining months. Plots of monthly mean hourly values against the cosine of the solar zenith angle were made on logarithmic
paper and found to fall on straight lines for each individual month. The slope of the line gives the index $\eta$ for each month. Table 1 gives the values of $\eta$ so obtained.

**Table 1.**

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$0.70 \quad 0.30$

Table 2 and 3 give the monthly mean values of absorption in db for each hour of observations; Table 2 for the August 1957 to April 1958 and Table 3 for May 1950 to February 1952. The cosine of the solar zenith angle for the
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corresponding hour on the 15th of each month is shown side by side with the measured absorption \( I \). Since the data for August 1953 was centred around the 5th and that of September 1953 around the 23rd, the values of \( I \) for these months correspond to the declination of the sun on the 5th and the 23rd. For the other months, they relate to the 15th day of the month.

From the two sets of observations, it would be seen that the absorption corresponding to the higher frequency 2.6 Me/s was consistently lower than that for 2.5 Me/s. However because of the nearness of the frequencies, it would not be proper to derive any general relation.

The mean value of \( \eta \) is seen to be 0.70 for the frequency 2.5 Me/c and 0.30 for 2.6 Me/s. The value of \( \eta \) for August and September 1953 is rather high; in these months the number of observations were small.

In calculating \( \eta \), the values of absorption only for the hours when foF2 was greater than 3.5 Me/s were considered. This is to avoid any effect of additional attenuation which might be associated with the closeness of the exploring frequency to the critical frequency of the E layer. That the slopes of the lines are not affected by deviative absorption due to the E layer is evident from the fact that for the higher frequency namely 2.6 Me/s the mean value of \( \eta \) has not decreased below the one shown by 2.5 Me/s. Had there been a
contribution from the deviative absorption it would have been larger on the higher frequency and would have decreased the slope rather than increased it.

Considering that the data available is only for 19 months, it would be premature to draw conclusions on the seasonal variations in the value of $\xi$, however it may be noted that the mean value of $\xi$ for summer months works out to be 0.36, for winter it is 0.69 and 0.74 for the equinoxes. It is interesting to compare these with the values of $\xi$ obtained by Bhonsle and Ramakrishnan\(^2\) for the $\beta$ region absorption from the 25 Mc/s cosmic noise measurements at Ahmedabad during 1967-53. They found $\xi = 1.1$ in summer, $\xi = 1.0$ in equinox and $\xi = 0.8$ in winter.

It may be noted that Appleton and Piggott\(^3\) from a sequence of observations extending over two solar cycles obtained a mean value of $\xi = 0.75$ at Slough.

In order to remove the seasonal variations in the measured values of $L$, the line $\log \rho \propto \cos \chi$ corresponding to each month was extended to give the value of absorption $L'$ corresponding to $\cos \chi = 1$. Table 4 gives for each month the value of the extrapolated absorption $L'$. Also shown in the table are the monthly mean sunspot numbers $R$ kindly provided by the Kodaikanal Astrophysical Observatory. In Fig.1 graphs of $L'$ against $R$ the sunspot number are given for 2.5 Mc/s and for 2.6 Mc/s. They are straight lines.
Fig. 1. Showing variation with sunspot number of absorption extrapolated for $\cos \chi = 1$.

Table 4.

$L' = \text{Absorption in db corresponding to } \cos \chi = 1$

$R = \text{Relative sunspot number}$

<table>
<thead>
<tr>
<th>2.5 Mc/s</th>
<th></th>
<th>2.6 Mc/s (Kodaikanal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month</td>
<td>L'</td>
<td>R</td>
</tr>
<tr>
<td>1957 Aug.</td>
<td>53</td>
<td>123</td>
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<tr>
<td>Sep.</td>
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<td>171</td>
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<td>Oct.</td>
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<tr>
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<tr>
<td>Mar.</td>
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<tr>
<td>Apr.</td>
<td>67</td>
<td>231</td>
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The equation of the two straight lines can be written in the form \( L' = L_0 (1 + \beta R) \)
where \( L_0 = 47 \) and \( \beta = 0.0020 \) for 2.5 Mc/s
and \( L_0 = 45 \) and \( \beta = 0.0013 \) for 2.6 Mc/s.

The slope of the line is only slightly lower for the higher frequency, but the line is shifted down by a significant amount.

The points corresponding to August and September 1958 seem to fall outside the lower line.

It is interesting to note that though the monthly mean sunspot number is well correlated with the absorption in the D region, it is difficult to find a day to day correspondence between the two. There are days with fairly low absorption corresponding to large sunspot numbers and vice versa.

Acknowledgments

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REFERENCES


DISCUSSION OF RESULTS

Variation of index n (Diurnal)

The observed value of the index $n$ in the equation $k \propto \cos^n \chi$ at Ahmedabad as also at many other latitudes is seen to be close to $0.75$ as against $1.5$ as would be expected from Appleton's derivation of equation (11) from Chapman's original assumptions.

In deducing a Chapman variation for the D region ionization, the recombination coefficient $\zeta$ was assumed to be constant with height. Nicolet (1951) and Appleton and Piggott (1954) have shown that $\zeta$ could as well be a function of temperature or pressure. Thus for $\zeta$ varying with height as $e^{-z}$ equation (11) becomes

$$\int k \, ds = \frac{4}{\sqrt{\pi}} \frac{e^2 \text{He}^2}{mc} \frac{\cos \chi}{(\omega - \omega_L)^2} \quad (21)$$

In the above derivation the letters have the same meaning as before. Thus the power of $\cos \chi$ is reduced to $1$ from $3/2$ in the earlier expression. The frequency dependence of absorption is not altered in the two cases.

In the present analysis, as remarked earlier, measurements were restricted to only two frequencies very near each other and no attempt to derive exact expression
for the variation of absorption with frequency was therefore made. However, $\int k \, ds$ is seen to be closer to the inverse square of the frequency rather than to the inverse frequency as reported by Skinner and Wright (1956), for the equatorial station of Ibadan.

For the equatorial latitude the situation appears to be as follows: In deriving equation (11) it was assumed that $\omega \ll \omega$. Skinner and Wright (1956) considered the case when this assumption is not valid and following Jaeger (1947) showed that for regions close to $\omega = \omega$ the law of absorption could be expressed by

$$-\log \rho \propto \frac{[\cos \chi]^{(3/2 - m)}}{\omega^{(2 - m)}}$$

where $m$ is a pure number, thus reducing both the powers of $\cos \chi$ and that of $\omega$ by the same amount. For the equatorial case, they showed that if absorption is assumed to take place at the level very close to $\omega = \omega$ then for $2 \text{ MeV}$, $m = 0.9$ making

$$-\log \rho \propto (\cos \chi)^{0.6}$$

thus explaining the observed dependence of absorption on the solar zenith angle as well as on the frequency of observation, at the equator.
The exact way in which the absorption varies with frequency in the \( \lambda \leq \omega \) region depends on the electron density distribution around this level. Booker (1935) showed that if the electron density were constant with height the absorption would be proportional to \((f + f_\perp)^{-1}\). On the other hand if the electron density were increasing more rapidly with height than the collisional frequency was decreasing, the total absorption could be proportional to \((f + f_\perp)^{-2}\).

**Seasonal variation of \( n \)**

Experiments on low frequency propagation have shown that in general the heights of the lower reflecting regions are lifted up during winter. The small increase in the index \( n \) observed in the present measurements during winter could probably be attributed to a change in the height of the absorbing region.

**Winter anomaly**

The existence of a winter anomaly in the shape of an extremely large absorption on certain days in middle and high latitudes in winter is absent at Ahmedabad. Echoes in low altitudes between 75 to 95 km on certain occasions and especially during winter have been reported. Appleton and Piggott (1954) have confirmed the large correlation between abnormally large absorption and the appearance of low level
echoes from lower layers of ionization. That this is a high or middle latitude phenomenon more common in winter is seen from their investigation of the data from an equatorial and two high latitude stations, one in each hemisphere. They report the absence of the winter anomaly at the equator and its existence in the local winters at the other two stations.

It is interesting to note the level at which the extra absorption takes place during disturbed winter days. Morrison (1960) working with extraterrestrial sources at Cambridge suggests the level to be around 60 km corresponding to \( V = \omega \) for the high frequency of 23.4 Mc/s used by him. The law of variation of absorption with frequency for this extra absorption, he shows to be inversely proportional to frequency, which it may be remembered is similar to that reported for equatorial stations. It may however be mentioned that Whitehead (1957) working at the same place had noted a variation for the disturbed attenuation inversely proportional to the square of the frequency.

Chapman and Little (1957) have summarized the results of absorption at auroral and subauroral latitudes. They show that at auroral latitudes the non-deviative absorption was very irregular and often much stronger than in sub-auroral latitudes. It was greater and more frequent by day than by night. They believe that the electrons that produce the absorption in subauroral latitudes are mainly caused by solar
Ultra violet light occurs in auroral latitudes the source is often the bombardment of the atmosphere by solar gas.

The present ideas on the subject indicate that the winter anomaly in middle and high latitudes is to be explained primarily in terms of particle radiation. Arguments have been given to explain the observed diurnal variation of the extra absorption. The non-existence of the anomaly in the tropics is clear from the present investigation. The occasional or general increase in absorption observed in low latitudes can be attributed to increase in solar wave radiation.

The deviative absorption

The method of analysis adopted in the present work has enabled us to separate the deviative absorption from the total absorption. The deviative absorption can be associated with the E layer. An accurate knowledge of the variation of the critical frequency of the E layer is essential for a more detailed analysis. Unfortunately the minimum frequencies recorded at the place on the available sweep frequency ionosonde recorder remained in general higher than the E layer critical frequency during most of the period of observations and no attempt could be made to analyse the deviative component further. A more powerful transmitter would have helped.
Magnetic disturbance

Little effect on the non-deviative absorption was expected during magnetic storms at the low latitudes. Nevertheless an attempt was made to check up on the same during the few magnetically disturbed days when absorption data was available. No obvious correlation was detectable between the two.

Sunspot numbers

Appleton and Piggott (1954) have shown for Slough a linear relationship between sunspot number (R) and absorption (L) of r.f. waves. The present analysis shows a similar variation at Ahmedabad. However, dL/dR at Ahmedabad is found to be five times smaller (Shirke 1959). Whitehead in a private communication has pointed out an error in the publication of the Slough results. He shows that the correct value of dL/dR is one third the published value, thus bringing the new value of the slope closer to that observed at Ahmedabad. He points out that the remaining variation could possibly be due to latitude differences between the two places.

The results obtained in the present study may be considered to be representative of the tropical latitudes not too near the equator. The variation of non-deviative absorption with \( \lambda \) depends essentially on the level of the
maximum absorbing region, the height distribution of electrons and their collisional frequencies around this level. In middle latitudes, the level appears to be higher than at equatorial latitudes. In the auroral zone, again the height of maximum absorption generally falls, due apparently to radiation of particle nature. At sub-auroral and high latitudes the height of maximum absorption is normally higher than at low latitudes but falls down to very low levels on certain days in winter.

REFERENCES

Elmore W.C. and Sands M., Electronic Expt. Techniques, 


Gnanalingam S. and Weekes K., The Physics of the Ionosphere, 


