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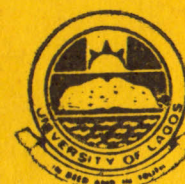
**FOR TOP-CLASS
LONG-DISTANCE RADIO**

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BY

E. O. OLATUNJI

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**UNIVERSITY OF LAGOS - 1989
INAUGURAL LECTURE SERIES**

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**FOR TOP-CLASS
LONG - DISTANCE RADIO**

An Inaugural Lecture Delivered at the University of Lagos
on Wednesday, 26th April, 1989.

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By

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"FOR TOP-CLASS LONG-DISTANCE RADIO"

Introduction

PERMIT me to begin today's lecture by registering my appreciation for the constant support of my wife who today is taking her largest dose of physics. I do not propose to make her do an examination on it later. At any rate you can guess her probable score in that eventuality since she has access to all relevant manuscripts. She and my children, most of whom are here today, had for long patiently borne the social shortcomings of an academic.

For another minute, let me also pay tribute to Chief J.O. Ola Ojo, late Principal of Wesley College, Ibadan, who as a fresh graduate from Fourah Bay College where he had just bagged two B.A. degrees in 1951 taught us Mathematics with style, and infused us all with his love of poetry. Today, I propose to de-mythologise physics; and if I do not completely succeed in that effort, it will be because of its being inextricably intervoven with mathematics and philosophy and my plea will be the same as that of the young man who was chided by his father for indulging over-much in poetical language. He replied: "Father forgive, I will no more verses make".

Definition of Scope

Radio communication is a very familiar aspect of modern life — so familiar that it may be taken for granted. Domestic radio, television and radio telephone are well-known forms of application of wireless radio. However, these items of equipment are the end points of a radio circuit, linking the transmitter on the one hand with the receiver on the other. The business of the day is rather with the medium linking these two end points, and what is in the purview of this discourse is how this medium, be it free air, empty space or a charged plasma, influences the behaviour and quality of the radio wave. References to transmitters, receivers or their associated antenna systems will be only in passing. For clarification we should say a word on precisely what a radio wave is.

A radio wave is a form of electromagnetic wave with frequency between 3KHz and 300GHz. The various frequency bands into which it can be sub-divided are illustrated in Figure 1. In this extremely wide frequency range there are specialised forms of service whose details can only be appreciated after further discussion. For now we note that V.L.F., L.F. and M.F. are mostly used in the ground wave mode, encompassing things like navigational communication and standard time services; but sky wave propagation by night is feasible.

VLF	LF	MF	HF	VHF	UHF	SHF	EHF	
3	30	300	3	30	300	3	30	300
kHz	kHz	kHz	MHz	MHz	MHz	GHz	GHz	GHz

Fig. 1: The Radio Spectrum

H. F. is predominantly devoted to sky-wave propagation while V.H.F. and higher frequency bands handle line-of-sight communication. All bands have some characteristic or other modified by the propagating medium but such modifications are best appreciated after some consideration of basic properties of the ionosphere.

Basic Facts About Ionosphere

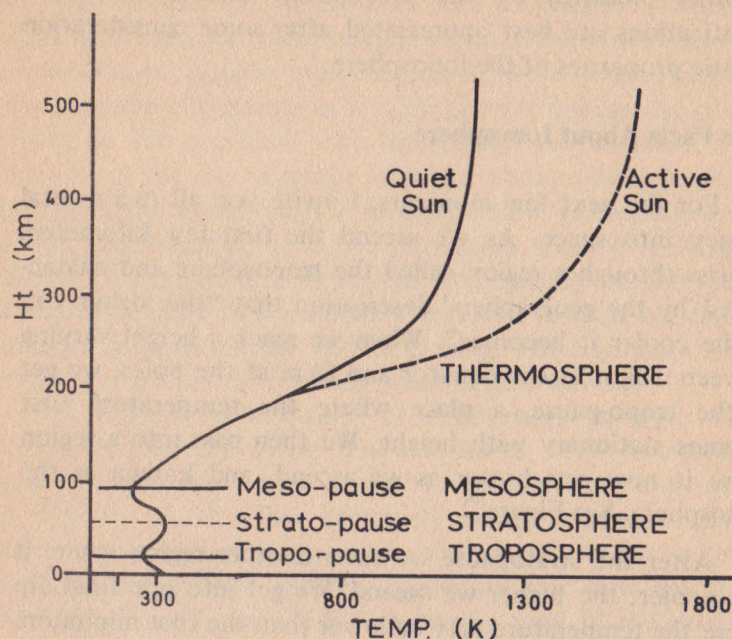
For the next few moments, I invite you all to a mental journey into space. As we ascend the first few kilometers we pass through a region called the troposphere and characterised by the geographers' description that "the higher you go the cooler it becomes". When we reach a height varying between 18km at the equator and 8km at the poles, we get to the tropopause, a place where the temperature first becomes stationary with height. We then pass into a region where it now gets hotter as we ascend, and known as the stratosphere. See Figure 2.

After the stratopause we enter another region where it gets cooler, the higher we ascend. We get into one final dip where the temperature may be lower than the first minimum. From here, it climbs up steadily in the thermosphere to reach a value reaching between 700 and some 1600 degrees absolute, depending on time of day, season and geographic latitude.

The first two regions — namely troposphere and stratosphere — being regions of atmospheric turbulence — are of homogenous composition, the relative composition of gases in them being the same as at the earth's surface. Higher up in the mesosphere and thermosphere, i.e. from about 50km up, diffusive separation of constituents sets in, making the lighter gases such as atomic oxygen, helium and hydrogen relatively more predominant in that order as we get into a region of charged gases. This region of highly ionized gases stretching from about 70km to about 1000km is known as

Fig. 2

HEIGHT VARIATION OF TEMPERATURE



the ionosphere. Distinctive combinations of composition, photochemistry and dynamics enable us to classify this height zone into layers as follows:

- 70 – 100km is called the D-layer
- 100 – 120km is called the E layer
- 120 – 180km is called the F1 layer

and higher up we have the F2 layer.

The basic theory of layer formation was published by Chapman (1931) in a pair of papers modelling a stratified atmosphere. The elegance of the theory lies in its simplicity of approach to a complex problem. A theory taking account of a heterogeneous non-isothermal atmosphere, irradiated by polychromatic radiation would have been quite daunting even for the modern electronic computer. It is to Chapman's credit that his theory turns out to be a fair approximation for the D- and E- layers, only being quite off mark for the F2 layer where ion movements play a dominant role.

Chapman's result for the rate of an ion formation, q , in a plane-stratified, mono-constituent isothermal atmosphere is given by

$$q = q_0 \exp(1 - z - e^{-z} \sec \chi) \dots \dots \dots (1)$$

where z is height measured from a reference level in units of the scale height of the ionizable constituent, χ is the solar zenith angle and q_0 the peak production rate for overhead sun. Allowance for sphericity of the earth-ionosphere system is made by replacing $\sec \chi$ in (1) with a special function called Chapman χ . The basic theory was improved upon by Bradbury (1938) and Bates and Massey (1948), while the effects of movements were considered by Duncan (1956), Martyn (1947), (1953), Matsu-shitta (1953), among others.

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Having made a few remarks about layer formation theory, we should briefly examine the structure of the ionosphere in our sort of latitudes particularly, bearing in mind that the electron density distribution in these low and mid-latitudes is the balance between the mechanisms of electron production, electron loss and peculiar dynamic forces.

Two satellite-based techniques will be briefly explained to illustrate the general trends of results. One is the Faraday rotation of the plane of polarization of satellite signals, and the second is the topside sounder technique.

When a wave is incident on the ionosphere, it is split into two magneto-ionic components each having elliptical polarization, and rotating in opposite directions. The net effect is a plane-polarized wave whose plane rotates as the path length varies. The angle R of rotation of the polarization plane is related to the electron density N and the magnetic flux B by

$$R = K \int BN \cos \theta, \sec i \, dh$$

where θ is the inclination of the wave normal with the magnetic field, i the local zenith angle of the ray and h the height. The differential fading rate in the actual ionosphere is related to that in a model ionosphere C by an expression of the form (Olatunji 1964)

$$\frac{R_1 - R_2}{R_{1c} - R_{2c}} = \frac{M_2 - M_1}{M_{1c} - M_{2c}} \frac{\int N dh}{\int_C N dh}$$

where the M-factor is given by

$$M = \frac{\int_0^h B N \cos \theta \sec i \, dh}{\int_0^h N dh}$$

and quantities are evaluated for two close ray paths.

From these the height - integrated electron density can be deduced from Faraday fading records. One such fading record is shown next. See Figure 3.

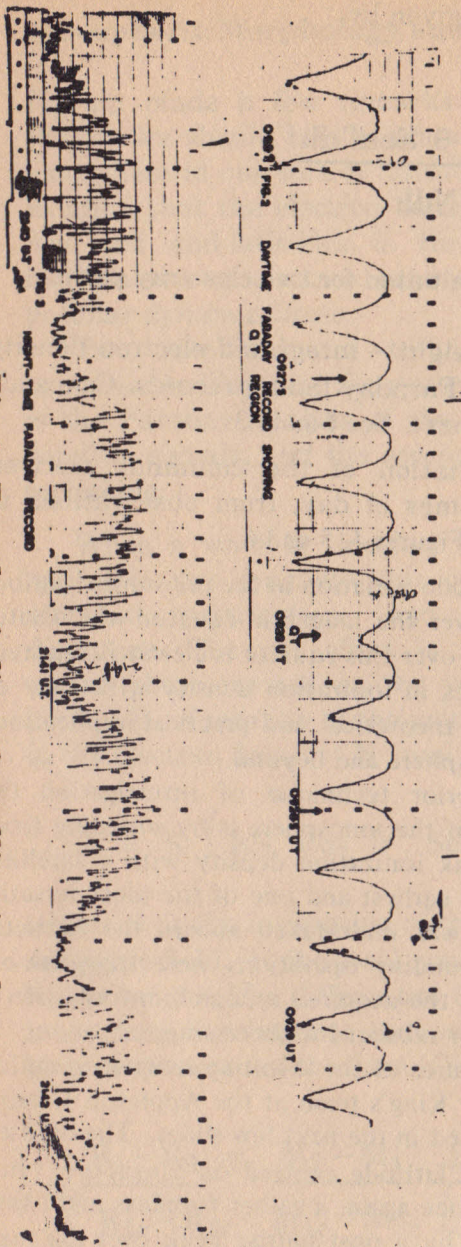
The latitude variation of the columnar electron density at various times of day, from observations in Ibadan is illustrated in Figures 4, 5 and 6.

A rather flat latitude variation in the pre-sunrise period, followed by a peak over the magnetic equator which later develops into a trough over this equator is clearly illustrated. These dramatic changes in ionization density with time of day and latitude have theoretical and practical implications for the equatorial ionosphere and beyond.

However, a superior technique of investigation the detailed morphology of the ionosphere is by sounding from above the level of peak ionization density with a satellite-borne ionosonde. The earliest and one of the most versatile sounding expeditions was undertaken aboard the Alouette satellite in 1963. Sounding operations were triggered off by ground control and the acquired ionogram information is telemetered to earth for subsequent processing.

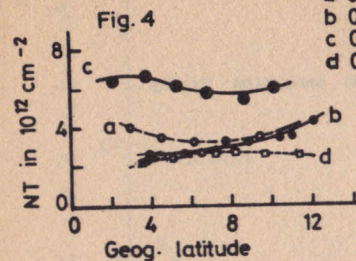
Some salient features of the resulting latitude variation obtained by us in Dr. King's team at the Appleton Laboratory, U.K. are illustrated in the next few slides. The data are for a range of $\pm 15^\circ$ latitude centred on Singapore. In Figs. 7, 8, 9a and b once again, a rather formless night-time distribution, followed by a post-sunrise peak over the mag-

Fig. 3. Faraday fading of satellite signals.



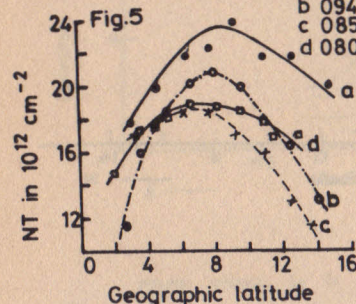
Latitude variation of NT:0230-0630

- a 0522
- b 0521
- c 0335
- d 0604



Latitude variation of NT:0700-1000 LMT

- a 0852
- b 0947
- c 0855
- d 0800



Latitude variation of NT:1200-2300 LMT

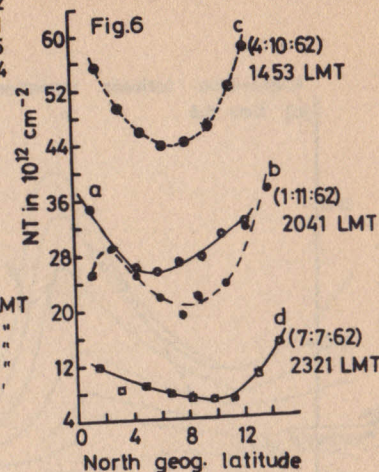
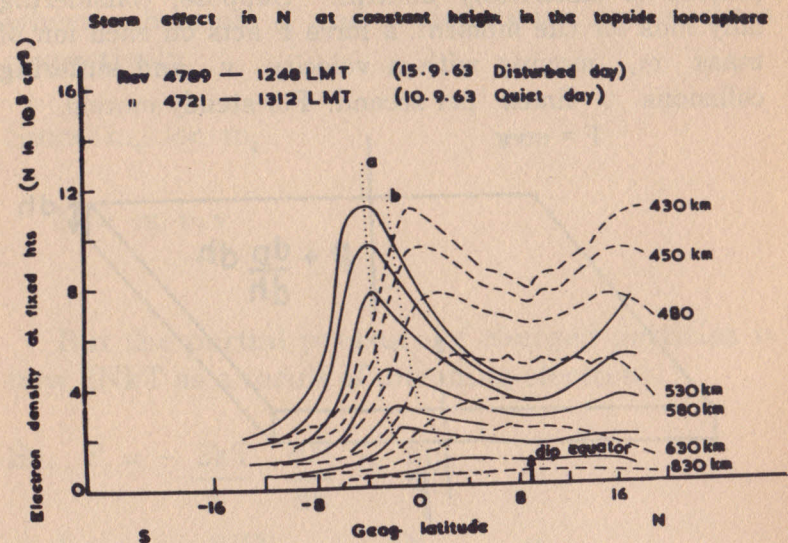
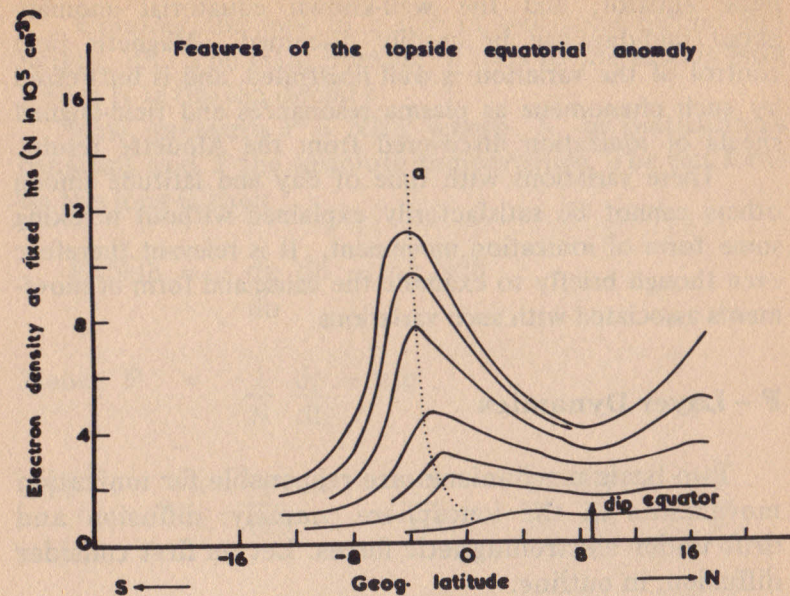
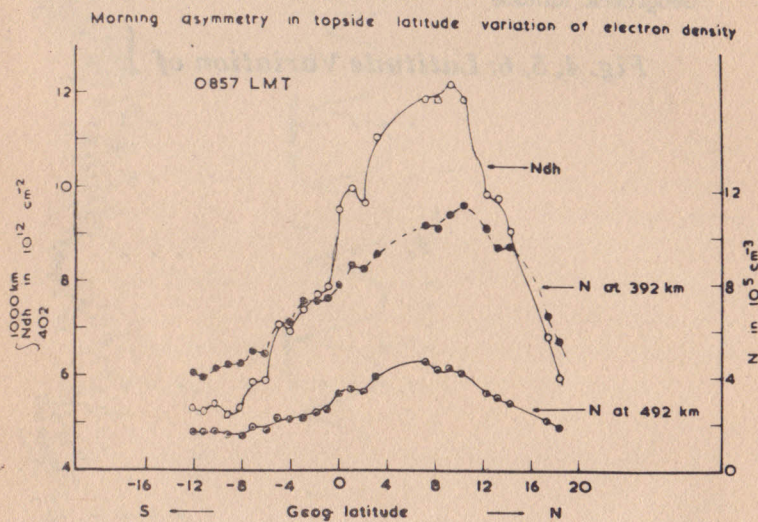
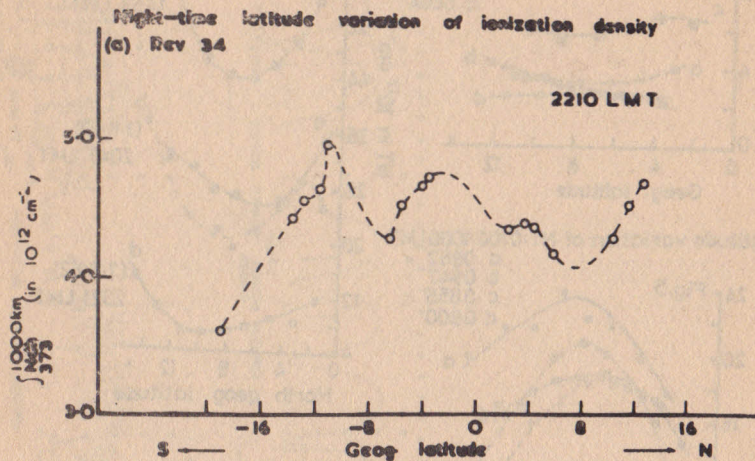


Fig. 4, 5, 6: Latitude Variation of \int



netic equator, and the well-known equatorial anomaly about mid-day can be readily discerned. Magnetic field control of the variation is well illustrated, and is buttressed by such phenomena as plasma resonances and field-aligned sheets of ionization discovered from the Alouette results.

These variations with time of day and latitude among others cannot be satisfactorily explained without invoking some form of ionization movement. It is relevant therefore even though briefly to examine the cause and form of movements associated with such variations.

F - Layer Dynamics

Two basic mechanisms are responsible for ionization movements in the ionosphere, namely: diffusion and drift under electromagnetic forces. Let us first consider diffusion, in outline.

Electrons and ions will diffuse together since the plasma is electrically neutral. Suppose, considering only ions for the moment, a force F acts on each ion of mass m , moving with a velocity v and suffering collisions ν times per second. For steady motion,

$$F = m\nu v$$

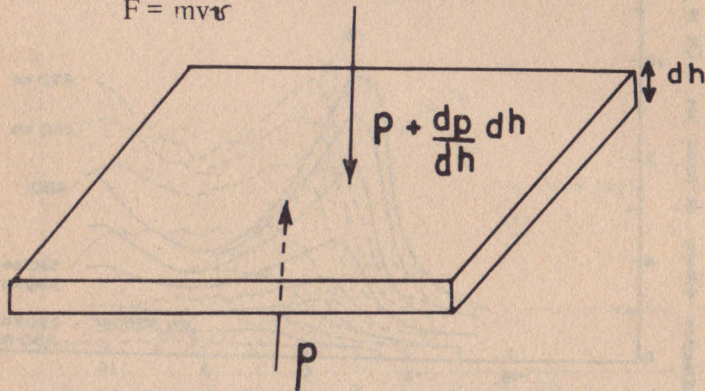


Fig. 10 : Plasma slab

Consider the ions in a slab of unit cross section and height dh . The total number of ions in the slab is Ndh where N is the ion density.

Now, pressure $P = NKT$ where k is Boltzmann's constant and T the absolute temperature. The net force on the ions is then

$$F Ndh = - \frac{dp}{dh} dh - mg Ndh$$

$$\text{Hence } F = - \frac{1}{N} \frac{dp}{dh} - mg$$

$$\text{and } v = \frac{F}{m\nu} = - \frac{kT}{m\nu} \cdot \frac{1}{N} \frac{dN}{dh} - \frac{g}{\nu}$$

Now including electrons $F = m_i \nu_i v + m_e \nu_e v$ where subscripts i and e denote ion and electron respectively.

Since $m_e \ll m_i$

$$F = m_i \nu_i v$$

But the partial pressure of charged particles is now $2NkT$ as a result of including electrons.

$$\text{So, } F = - \frac{2kT}{N} \frac{dN}{dh} - m_i g$$

$$\text{and } v = - \frac{2KT}{m_i \nu_i} \cdot \frac{1}{N} \frac{dN}{dh} - \frac{g}{\nu_i}$$

Now putting $H_i = \frac{kT}{m_i g}$ and $dz = \frac{dh}{H_i}$

$$v = - \frac{2g}{v_i} \left(\frac{1}{N} \frac{dN}{dz} = \frac{1}{2} \right)$$

However, v_i is proportional to the neutral particle density n and $n = n_0 e^{-h/H_0}$ where H_0 is the neutral particle scale height.

We may therefore write

$$n = n_0 e^{-kz} \text{ where } k = \frac{H_i}{H_0}$$

Since $v_i \propto N$, or $v_i = An$, say

$$v_i = An_0 e^{-kz}$$

$$v = - d e^{kz} \left(\frac{1}{N} \frac{dN}{dz} + \frac{1}{2} \right)$$

$$\text{where } d = \frac{1}{An_0}$$

The electron density continuity equation for the F region is $\frac{\delta N}{\delta t} = q - \beta N - \frac{\delta}{\delta h} (Nv)$

where the divergence term has been taken one-dimensionally. Taking this last term in the last equation as $-\frac{\delta}{\delta z} \left(\frac{Nv}{H_i} \right) = D$,

it readily follows that

$$D = \frac{d}{H_i} e^{kz} \left\{ \frac{\delta^2 N}{\delta z^2} + (k + \frac{1}{2}) \frac{\delta N}{\delta z} + \frac{1}{2} k N \right\}$$

While this diffusion term had at times been considered 3-dimensionally, above suffices to illustrate the problem involved in evaluating the effect of diffusion, and the association problem of solving the electron density continuity equation.

At this stage, Mr. Vice-Chancellor Sir, I can almost hear a few people saying "What is all this to do with F.R.C.N. or my favourite T.V. programme?" To such people I say, "A little more patience". They do not have a better explanation of events though.

What then is the effect of ionization drift on the ionosphere?

Ionisation Drifts in Ionosphere

The story is like that of the egg and chick. When there is an e.m.f., free charges will move. When these free charges move across a magnetic field, a further e.m.f. is produced. I prefer to emphasize the atmospheric dynamo aspect as this throws a lot of light on ionospheric behaviour near the equator.

For a charge e of mass m moving in an electric field E and u collisions per second, we have $m \nu u = e E$

where u is the mean drift velocity. This leads to a current density.

$$j_0 = neu = \frac{ne^2 E}{mv} = \sigma_0 E, \text{ say.}$$

Taking account of positive and negative charges,

$$\sigma_0 = e^2 \left(\frac{n_+}{m_+ v_+} + \frac{n_-}{m_- v_-} \right)$$

If $n_+ = n_-$

$$\sigma_0 = ne^2 \left(\frac{1}{m_+ v_+} + \frac{1}{m_- v_-} \right)$$

Taking account of the earth's magnetic field, Chapman and Bartels (1940) showed that the conductivity becomes:

$$\sigma_1 = ne^2 \frac{v_+}{m_+(v_+^2 + w_+^2)} + \frac{v_-}{m_-(v_-^2 + w_-^2)}$$

where w is the angular gyrofrequency. Also, as a result of the magnetic field B , another current, called the Hall current, flows in a direction perpendicular to both E and B and gives a conductivity

σ_2 where

$$\sigma_2 = ne^2 \left\{ \frac{w_+}{m_+(v_+^2 + w_+^2)} - \frac{w_-}{m_-(v_-^2 + w_-^2)} \right\}$$

The total conductivity is $\sigma_1 + \sigma_2 = \sigma_3$ and the height-integrated conductivity k is

$$k = \int \sigma_3 dh.$$

Using spherical polar coordinates and employing current stream function R such that current

$$I_x = \frac{\delta R}{\delta x} \quad I_y = \frac{\delta R}{\delta y}$$

Chapman (1913), in a way we do not have time to develop, showed that

$$\begin{aligned} & \frac{\delta(vZ)}{\delta\theta} + \frac{\delta(u \sin\theta Z)}{\delta\theta} \\ &= K \left\{ \frac{\delta^2 R}{\sin\theta \delta\theta^2} + \frac{\delta(\sin\theta \delta R)}{\delta\theta} \right\} \\ & - \left\{ \frac{\delta k}{\delta\theta} \left(\frac{\delta R}{\sin\theta \delta\theta} \right) + \frac{\delta k}{\delta\theta} (\sin\theta \frac{\delta R}{\delta\theta}) \right\} \end{aligned}$$

Here, velocity v is perpendicular to u and Z is the vertical component of the earth's magnetic field. Using the value of k deduced above in the last formula, systems of ionospheric currents can be obtained which explain many features of geomagnetic variations and hence we may be reasonably certain that these overhead currents exist.

The distribution of the various conductivities with height is shown in the next diagram.

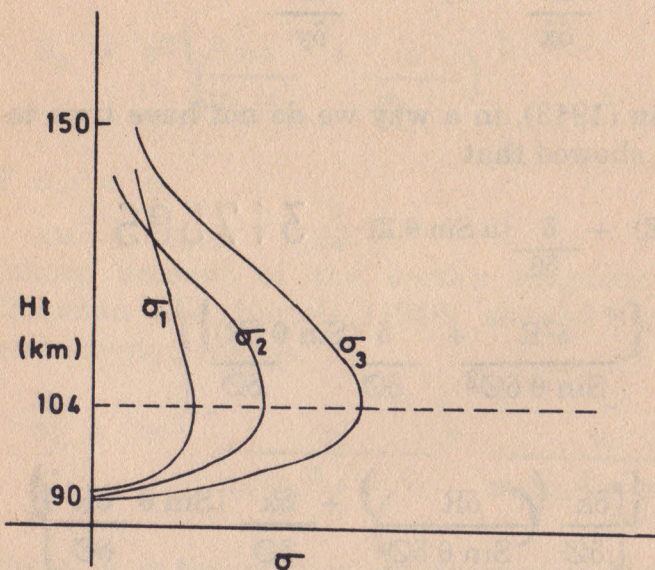


Fig. 11: Height variation of conductivity

σ_3 is most enhanced near the magnetic equator where the polarization field developed through charge separation across the boundaries of the ionosphere completely suppresses vertical currents. The result is an enhanced horizontal current called the equatorial electrojet which explains many features of magnetic and ionospheric variations as already mentioned.

As regards ionisation drifts per se, Martyn (1947), using the principles outlined above, obtained expressions for drift velocities for cases with a negligible and a substantial polarization field. Subjecting an initial α - Chapman equilibrium layer to these drifts, he showed that a downward drift reduces the peak ionisation density. What happens to the corresponding height varies with the height profile of the drift. An upward drift increases both the maximum ionisation density as well as the height at which it occurs.

Link-Up With Outer Space:

It is very pertinent to examine how the ionosphere is linked to outer space. This inter-relationship comes primarily through the influence of the sun. What then are the salient facts about the sun?

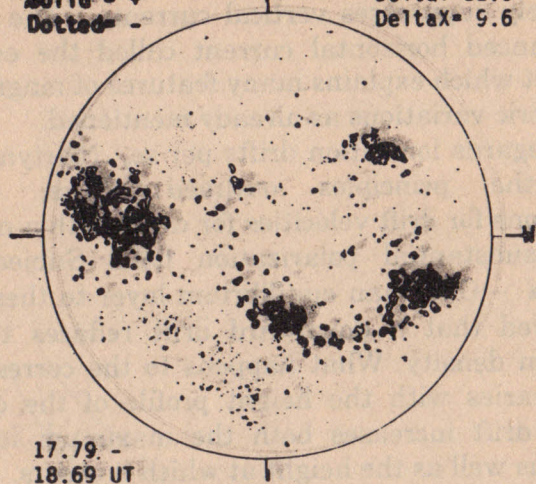
First, it has a dark interior whose diameter is about 118 times the earth's diameter. It is like a cauldron of altogether gaseous matter whose temperature varies from some 6000 Kelvin for the visible part to about 10^6 K in places. Some groups of dark spots which are centres of strong magnetic fields are known to be present in the solar interior. These sun-spots, some of which are several times the size of the earth, are photographed daily, and are shown on the next slide.

$L_0 = 217.19$

MT. WILSON MAGNETOGRAM

Solid = +
Dotted = -

Delta Y = 12.6
Delta X = 9.6



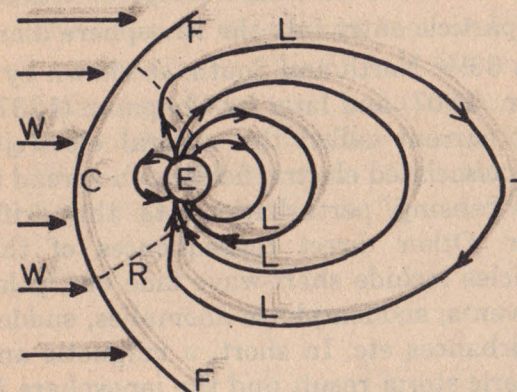
SACRAMENTO PEAK CORONA (1.15 Rad11)

Since the sun has a rotation period of 27 days, an event caused by these sunspots tends to recur at 27-day intervals. From time to time also, some portions of the sun become extra-active in emitting a particular type of radiation — say x-rays, ultra-violet or others; and the effect shows up in form of extra ionization in the ionosphere. An intense solar flare can lead to so much extra ionization and its attendant attenuation of radio waves as to cause a radio black-out. It then becomes impossible to receive long-distance radio waves, on a global scale.

Equally interestingly, the sun is known to emit a continuous stream of charged particles, with an intensity that varies with time. When this plasma with its associated magnetic field impinges on the earth's magnetic field, a magnetic shock is felt on earth in form of a so-called sudden commencement. The prognosis of events is best illustrated on the next slide.

Fig. 13

EARTH & MAGNETO - SPHERE



- E - Earth.
- T - Geomog. tail.
- C - Magnetospheric cavity.
- L - Field lines.
- W - Solar wind.
- R - Escape route for particles.

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This shows the solar plasma, the magneto-spheric cavity that is produced from this interaction, and the distorted magnetic field of the earth evidenced by the geomagnetic tail. The magnetospheric cavity is a region of weak magnetic fields and can link up with the ionosphere by means of hydromagnetic waves. The resulting leakage of charged particles causes particle entry into the ionosphere along latitudes close to $66\frac{1}{2}^\circ$ North and South, as shown by a theory by Stomer, (1907) and later by Chapman (1937). An intense ring current called the auroral electrojet develops and the associated electric fields soon spread to other latitudes, causing perturbations to the drifts discussed earlier. Other direct consequences of this dumping of particles include short-wave fade out, polar cap absorption events, sudden phase anomalies, sudden ionospheric disturbances etc. In short, a magnetic and often an ionospheric storm result and the ionosphere in mid-latitudes can sometimes be considered as going mad. Radio communication via this part of the ionosphere is therefore often unpredictable and unreliable.

There are other sources also, beside the sun, emitting radio waves within and outside our own galaxy. Such radio emissions are often undesirable and constitute noise. Thunder-storm activity is a prominent source in this regard. Equipment atimes has to be designed with this noise factor in mind, so as to make radio reception attain better quality.

Magneto-Ionic Theory

We have spent some time examining the ionospheric medium and some of its characteristics. Equally vital to the subject of today's lecture is propagation theory for a magneto-ionic medium, and this we turn attention to, briefly.

Two main factors make the ionosphere different from free space, in so far as radio communication is concerned. These are the fact that the medium is ionized, and the fact that the earth's magnetic field is present, thus rendering the medium anisotropic and hence, doubly refracting.

The relevant theory has been well developed and is well summarized in Appleton - Hartree's formulas for the refractive index and polarization, which I merely quote here, assuming familiar monenclature.

The refractive index n of the medium is related to the normalized variables X , Y and Z by the relation.

$$n^2 = 1 - \frac{2x}{2(1-jz) - \frac{Y_T^2}{1-jz-x} \pm \sqrt{\frac{Y_T^4}{(1-jz-x)^2 + 4Y_L^2}}}$$

where $x = \frac{f_N^2}{f^2}$, f_N being plasma frequency, and f the

wave frequency,

$$Y = \frac{Be}{mw}$$

w being $2\pi f$

subscripts T L denote values transverse and parallel to the wave normal respectively, and

$$Z = \frac{v}{w}$$

$$j = \sqrt{-1}$$

Also, the wave polarization

$$R = \frac{-j}{2Y_L} \left[\frac{Y_T^2}{1-jZ-X} \pm \sqrt{\frac{Y_T^4}{(1-jZ-X)^2} + 4Y_L^2} \right]$$

These formulas are very handy for example in ray tracing routines calculation of angle of arrival, estimation of polarization, ionospheric loss, group path and any other ray parameter in any ionized medium. By their nature, propagation characteristics in non-ionized media or problems such as wave-guide mode propagation in an earth-ionosphere system are excluded.

As an application of the polarization formula in our sort of latitude where propagation is under quasi-transverse conditions i.e.

$$\frac{Y_T^4}{|(1-jZ-X)^2|} \gg 4Y_L^2,$$

we find that R becomes nearly 0 or ∞ respectively near reflection for the ordinary and extraordinary waves. Hence either wave is plane - polarized, thus suggesting the correct orientation for a transmitting or receiving antenna.

As a special application of the index formula, the wave attenuation under conditions of quasi-longitudinal propagation, i.e.

$$4Y_L^2 \gg \frac{Y_T^4}{|(1-jZ-X)^2|}$$

the path-integrated absorption is readily obtained as indicated.

$$\text{Putting } n = \mu - j\chi$$

$$n^2 = \mu^2 - \chi^2 - 2j\chi = 1 - \frac{X}{1-jZ \pm Y_L}$$

From the imaginary part, the total attenuation

$$\begin{aligned} \int k dh &= \int \frac{w\chi}{c} dh \\ &= \frac{w}{c} \int \frac{1}{2\mu} - \frac{XZ}{(1 \pm Y_L)^2 + Z^2} dh \end{aligned}$$

Some of the major characteristics of absorption can be deduced by comparing results based on experiments or model calculations with the prediction of this last formula or other appropriate expressions.

Absorption Results

There are two general approaches to deduction of ionospheric absorption. One is based on theoretical computations, using say the phase integral method i.e. evaluating the imaginary part of the complex integral.

$$L = \int n dz$$

where z is complex height

Using this method (Olatunji, 1983), it is relatively easy to elucidate the variation of absorption with any desired parameter, using model profiles for N , ν , Y in above formulae. It is also relatively easy to demonstrate the following:

- (1) that absorption occurs under quasi-transverse conditions near the reflection point, whatever the initial condition of propagation;
- (2) that substantial absorption occurs in the F-region, for waves penetrating that layer, unlike earlier general belief;
- (3) the form of frequency law for ionospheric absorption used by some earlier workers (George, 1971) may lead to inaccuracies in the F-region.

Using this computational technique, Ezimuo (1987) one of my research students, verified a form of empirical frequency law which will be expected to be more consistent with observation for low and middle latitudes.

On the experimental side, a number of workers, including Skinner (1964), George (1971), Gnanalingam (1974), Mbipom (1971), Oyinloye (1978) have examined characteristics of low-latitude ionospheric absorption. Results have not always been consistent however and large gaps remain in our understanding of the operating

mechanisms. Using the A3 technique, we have carried out studies of time variations of ionospheric absorption on frequencies 4.9 and 7.1 MHz from Cotonou and Ilorin respectively.

Permit me, Mr. Vice Chancellor, Sir, to add one or two details about this project as any success we might have had will encourage those coming behind and mistakes will serve as a lesson. We collected six transmitters from a pile of demobilized equipment in the Nigerian Railways, Ebute-Metta; and with a lot of sweat got them into operating shape, with three in Lagos and three in Nsukka on a two-way circuit. Since the Nsukka end had more problems with equipment spares than we did, the program had to switch to monitoring commercial transmissions and was re-designed. My staff student, Mrs. Shamsi, spent about seven years to complete her Ph.D. research on this project. I must add that we all learnt what nothing else but the sheer experience could have taught us. I summarize the highlights of this investigation as follows:

The Loss L is deduced from the relation.,

$$L = \cos \alpha_1 \cdot 20 \log \frac{E_n}{E_d} \frac{S'_n}{S'_d} \frac{G_n}{G_d} T \cdot \frac{G_n}{G_d} R$$

where subscripts n and d refer to night and day respectively, E is signal strength, S' the slant path, α_1 the incidence angle on the ionosphere and G_T the transmitter antenna gain, while G_R is the corresponding value for the receiver antenna.

Some calculations of possible attenuation of various modes and examination of ionogram information soon established that the dominant modes were 1F, but 1E_s

on occasions when blanketting E_s occurred. The incidence of transparent E_s could however permit a mixed mode though this was rather uncommon.

Continuous recording of signal strength from pre-sunrise hours to midnight facilitated the study of time variation.

Representing loss for either of the above two circuits in the form $L = L_0 \cos^n \chi$ where χ is the zenith angle, it was found that there was a systematic variation such that post-noon values of n exceeded those for the pre-noon period, in agreement with A1 results for Ibadan by Skinner (1964).

Often, in predicting ionospheric loss, the sunspot number R is used in a regression relation as a basis for forecasting. The standard practice is to express the absorption as a function of the 12-month sliding mean sunspot number. However, in this investigation, the loss on the lower frequency was found to correlate better with the monthly mean sunspot number R_z while for the higher frequency, there was better correlation with R_{12} . In fact the whole question of short-term variability of ionospheric parameters needs to be more properly investigated; and some work is currently being done on this.

On the question of the seasonal variation, while there was no significant discrepancy between the diurnal and seasonal indices in a $\cos \chi$ form of representation on the lower frequency, for the higher one while the diurnal index was about 1.0, the seasonal index was 6.4. In fact, to generate the annual minimum from the maximum on the basis of a single term $\cos^m \chi$ relation requires an index of 12 for Radio Kwara.

A form, $L = (L_1 + L_2 \cos^m \chi) \cos^n \chi$ was found to be a better fit to observe results.

An intense attenuation at sunrise in the ionosphere was found to characterize each frequency and is believed to be due to deviative absorption near a layer critical frequency. An apparent enhancement of signal strength occurs around sunset which requires further confirmation and explanation, but is suspected to be due to focusing effects.

Ionospheric Storm Effect On Absorption

While the effect of magnetic storms leading to ionospheric disturbance had been found from time to time for the lower ionosphere, it was sometimes claimed that there are no such effects for the F region. Using A3 data referred to above, one of my research students, Ladele (1987) found substantial storm effects in F layer absorption for the period 1979/80, a period of maximum sunspot activity. The result, an enhanced absorption by day, and a reduced one by night, relative to quiet periods, is illustrated in Fig. 14

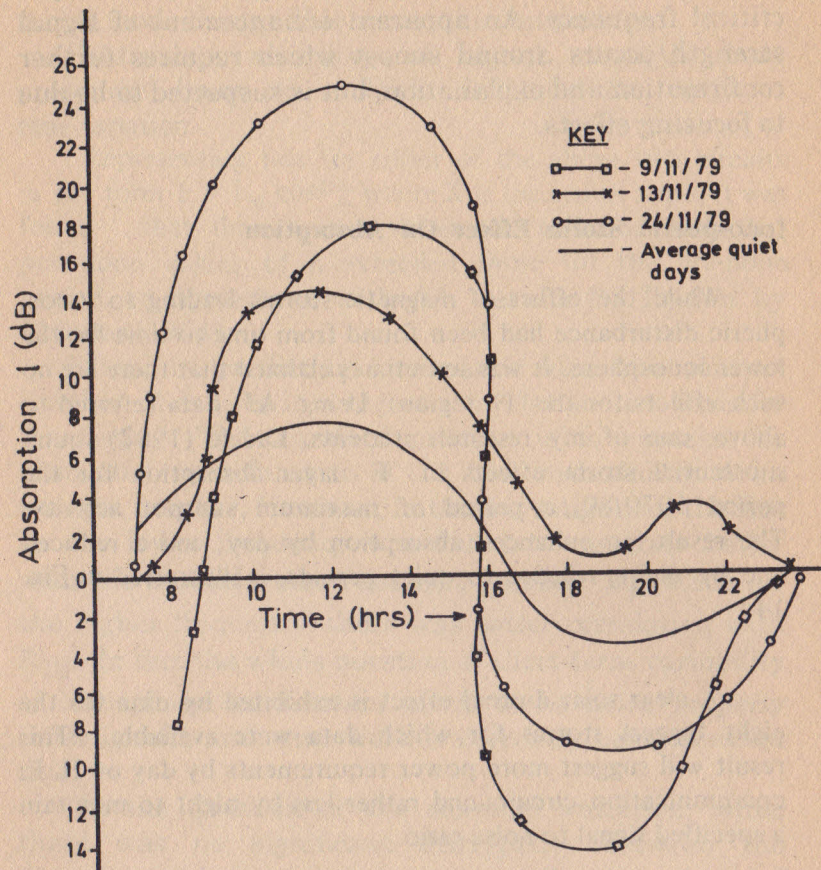
A clear solar diurnal effect is exhibited by data for the eight biggest storms for which data were available. This result will suggest more power requirements by day on H. F. communication circuits and rather less by night to maintain a specified signal to noise ratio.

Some More Features Near The Equator

Two more features of the equatorial ionosphere that may influence radio propagation are still to be mentioned. These are equatorial spread F, and equatorial sporadic E.

Fig. 14

GRAPH OF ABSORPTION AGAINST TIME FOR NOVEMBER 1979



As seen on an ionogram, spread F manifests itself in two main categories. Instead of a clean $h' - f$ trace, there may be something rather like a fox tail at the high frequency end, giving frequency spread. There may however be a woolly trace for all frequencies, giving range spread. The characteristics have been studied by many workers including Lyon, Skinner and Wright (1960), Chandra and Rastogi (1972), and Odutayo (1988). Its most notable effect on radio communication is fast fading of the radio star scintillation type. This is rather prevalent by night on all radio frequencies but is largely absent by day. Its diurnal development and seasonal characteristics have been more closely investigated by Odutayo (ibid). The size and orientation of the irregularities producing it have been well reported on by above-cited workers and have been recently probed by radar and multi-pronged techniques. Spread F correlates negatively with magnetic disturbance at low latitudes but positively at middle and high latitudes.

As regards sporadic E, the term is used to describe an intense sheet of ionization usually embedded in the E layer. While its thickness is of the order of 1 km, its lateral extent can be up to a few 100 km. Basic types recognized include the equatorial type which is transparent and occurs within $\pm 6^\circ$ of the magnetic equator, the temperate type and the auroral type. There is a blanketing type that is opaque to low F region frequencies.

It is widely accepted that a mechanism based on wind shear (Dungay 1959, Farley 1963), is mainly responsible although particle dumping can contribute in the case of auroral E_s .

q-type E_s is a normal daytime phenomenon and correlates with the equatorial electrojet whereas temperate-type E_s exhibits peak occurrence by night (Oyinloye 1987) and has a summer maximum. Blanketing E_s can support

H.F. communication by reflection, although its occurrence frequency is sharply reduced in the dip equator zone.

V.H.F. communication via sporadic E is normally by a scattering process for weak signals but is specular for stronger signals (C.C.I.R., Delhi 1970).

Specialized Considerations

Mr. Vice-Chancellor, Sir, Distinguished Ladies and Gentlemen, at least one thing has become clear thus far: that without a large stock of knowledge like as outlined above, and the proper application of the same, top-class radio communication will be a mere mirage. We now proceed to examine some salient features implied by each mode of propagation if we are to have very satisfactory performance.

V.L.F./L.F.

In the very low frequency or low frequency band, the limitation of bandwidth and attendant low data rate are obvious disadvantages. So also is the high cost of the antenna system. However, the low attenuation and the possibility of under-water communication are on the positive side of the balance sheet. Major applications, as noted above are for radio-navigation and standard time services.

The wave-guide mode, with its theory developed by Wait (1962), is the dominant transmission mode, with the earth and the ionosphere acting as the wave guide.

As pointed out recently by Pan Weiyan and others (1987), while earlier techniques like the C.C.I.R. curves of reflection coefficient versus vertical equivalent frequency or the use of the reflection coefficient matrix by Budden (1961) may be used, a full wave theory is required to give an adequate representation of field strength.

Multi-mode interference will as a rule be present since many propagation modes are possible, and neighbourhoods of interference nulls have to be avoided for good signal

strengths. A knowledge of both ground conductivity and air refractivity is essential for calculation of field strength or for equipment configuration.

Medium Frequencies

This is the band that is heavily used in Nigeria for state radio broadcasts. However, the geographical location of state capitals where the broadcast is done is such that attempts to cover the whole of the state effectively may lead to interference with neighbouring states. Political advantage may outweigh technical expediency in such a situation. Directional antennas, with their attendant extra cost, will ameliorate the situation, and judicious frequency allocation will also go some way in reducing channel interference.

For the ground wave, the dominant parameter required is the ground conductivity. While some work has been done for limited zones in Nigeria (Owolabi & Ajayi 1987), a lot more still needs to be done to provide conductivity data which will be needed for signal strength predictions.

For the sky-wave, which is a possibility on M.F. at night, one extra source of loss is polarization coupling. The signal arriving at the ionosphere may not be equal to that in the ionosphere or the one arriving from the ionosphere may not be equal to that in the receiving antenna. This is polarization coupling loss, and results in an undue amount of the wave energy being transferred to the extra-ordinary wave. Allowance for this loss may be made for example by use of the C.C.I.R. formula.

$$L_p = 180(36 + \theta^2 + I^2)^{-1/2} - 2 \text{ dB/terminal}$$

(Sain & Reddy 1987); where L_p is the loss, I the dip angle and θ is the path azimuth from magnetic East-West, both angles being measured in degrees.

As far as the ionospheric loss itself is concerned, enough has been said above to suggest the variability of this with time of day, season, frequency, sunspot activity etc, even

for the M.F. band. From night time observations of field strength for different circuits round the year for several years, some reasonable estimate may be made for these corrections. No such systematic data exist for Nigeria however. Even for the European Broadcasting Area, large gaps still exist in available data. In India, approximate allowance is made using an all-year so-called Cairo curve (Sain & Reddy 1987).

H. F. Band

One point that needs high-lighting in the African sector is the scantiness of ionosphere data for H. F. communications. The peak period for data acquisition is the period leading up to the International Geophysical Year in 1957/8. Then, Ibadan and a number of African stations operated mainly by the French, acquired ionosonde data on a daily routine basis. For the past 25 years or so, most of these stations including the Ibadan one, had stopped data recording. The business of using data for ionospheric predictions for communication purposes is therefore left to rather generalized results from World Data Centres.

H. F. predictions in India are based on data acquired from 40 ionosphere sounding stations, most of these located in India (Main & Reddy 1987). China uses 3^Q (Mannu & Zhenchong 1987). The Indian data span over a period of 3 solar cycles, i.e. 33 years. We must however hurry to underscore some of the technical aspects of H.F. predictions.

The ionospheric parameters employed include the layer critical frequencies — foE & foF2, the maximum usable frequency (MUF) with indications of their upper and lower deciles, the lowest usable frequency L.U.F., the optimum traffic frequency FOT, the polarization coupling loss and ionospheric absorption loss. Indices in common use are the sunspot number, solar U.V. 10cm flux data, solar flare and x-ray flux data, the IF2 index, and geomagnetic indices. With this medley of indices and parameters, we can only

select some salient points demanded by quality radio transmission.

The sunspot number continues to be used, even though it is not a direct indication of solar wave radiation. It however correlates quite well with many of the parameters previously mentioned; and often forms the basis of predicting these quantities. We may also note that the latitude gradients mentioned earlier in connection with the equatorial anomaly will, as shown by Reddy et al (ibid) affect the M.U.F. A ray reflected from say the F layer at a given latitude may on second hop penetrate the F region at a different latitude.

Since quiet-day absorption is what has been normally correlated with sunspot number, the ionospheric storm effect on absorption mentioned earlier has got to be separately allowed for. Similarly, corrections as a result of variations in time of day, season and frequency can be applied, as detailed in references cited earlier. It may be added here that short-term variations in absorption or foF2 or MUF and others are not well taken care of by the 12-month sliding mean sunspot number for two reasons. The input data require a minimum of six months values ahead of the time for which they are being used. Further, periods shorter than twelve months tend to be smoothed out.

Prior to the time when computers came into popular use, the M.U.F. was estimated by multiplying the critical frequency by a factor based on specular reflection from an assumed height. A better estimate can be obtained by modelling the ionosphere and carrying out a ray-tracing routine. One of my research students, Umar A (1988) has developed a 2-dimensional ray-tracing computer program with provision for estimating ionospheric absorption. The full versatility of the technique can only be achieved in an extension to three dimensions.

A-1 absorption data obtained as a result of global cooperation during the I.G.Y. have been used by George (1971) as a basis of calculating absorption on any desired

frequency. A detailed re-examination has however shown (Olatunji 1982) that this procedure needs modification for F layer reflections.

Lastly, apart from these enumerated steps to predict H.F. signal strengths fairly accurately, E_s echoes and spread F can affect the quality of reception in this frequency band. Strong E_s reflections may be present by day, especially when blanketing occurs, and fast fading will generally occur at night, as a result of spread F irregularities. Such fast fading will pose less problem on magnetically disturbed nights as a result of its inverse correlation with disturbance in low latitudes.

V.H.F and Above

This frequency band has, since the evolution of satellite communications received more and more attention. Within the limited time left, consideration will be restricted to modes of propagation, and the mechanisms of attenuation.

Three modes of propagation can be demarcated from our current viewpoint. First, we can have ionospheric reflection in the frequency range 30 to 60 MHz say, via the sporadic E layer. Next, we can identify line-of-sight propagation, incorporating things like television broadcasting, earth-to-satellite communication, and terrestrial relay systems such as microwave links. Thirdly, there is the so-called trans-horizon propagation involving diffraction, tropo-scatter and any other mechanism that involves a field wider than the radio horizon.

V.H.F. reflection or scatter from the equatorial sporadic E layer has long been recognised as a potential means of long-distance communication in low latitudes but rather little has been done about it.

The flexibilities and potentialities of satellite communication and other line-of-sight systems are being more vigorously explored. Such is the possibility that one can use different channels in a given band for say television, telephone-

facsimile etc, or watch television programmes of foreign countries if one has the requisite antenna system. System diversity is sometimes used in this and other modes to improve signal quality. This term applies when for example we use two vertically separated antennas to receive the same signal. The spacing is determined such that the signals received are independent of each other and hence fades on one channel tend to be compensated by peaks of the other. This is space diversity. In a similar way, two different, suitably chosen frequencies can be used to transmit the same signal in frequency diversity mode, with improvement in signal quality.

Thirdly, in diffraction and tropo-scatter modes, signals are scattered coherently or otherwise from obstacles, or discontinuities in atmospheric temperature, air density and the like.

Attenuation of waves in the ionosphere is already covered in earlier remarks. For propagation though the troposphere, attenuation by rainfall, water vapour and oxygen are the most significant. According to Minggao et al (1987), specific attenuation by rainfall can be approximated by a power law of the form $\gamma_R = \lambda R^\alpha$ where R is the rainfall rate and coefficients k and γ depend on the microstructure of the rainfall. The total gaseous absorption in a path length r is given by

$$A = \int \gamma_a(r) dr$$

where $\gamma_a(r) = \gamma_w(r) + \gamma_o(r)$ and γ_w and γ_o are the specific attenuation of water and oxygen respectively.

Water vapour has strong absorption lines at 22.3, 183.3 and 323.8 GHz and at a number of sub-EHF frequencies. Keeping away from these frequencies will reduce absorption due to these sources.

Other causes of attenuation include interference caused by rain scatter when an earth-space link crosses a terrestrial link, scatter by non-rain hydrometeors, dust storms, vegetation, among others. Solutions in some of these cases exist in form of avoiding the cause of the attenuation.

Summary and Conclusions

Mr. Vice-Chancellor, Sir, we must now crystallise our arguments by way of a summary and drawing necessary conclusions.

After defining the radio spectrum, we enunciated some basic principles in ionospheric physics, with emphasis on morphology and dynamics. Consideration was next given to ionospheric radio propagation with outstanding characteristics and in particular radio wave absorption being discussed.

The role of adequate propagation data and of a good understanding of the relative roles played by such data for effective radio communication were high-lighted. It was demonstrated that an efficient prediction system is the clue to top-quality radio communication.

Specific aspects of radio communication, from very low frequencies to extra-high frequencies were discussed, with indications being given of relative advantages and problems.

What then are the guidelines to follow if we are to have top-class long-distance radio communication?

First, we must re-mobilize for a sustained acquisition of essential data for the prediction of radio propagation parameters. This will translate to equipment acquisition and effective maintenance and usage of the same.

Secondly, a body needs to be put in place that will be charged with local prediction of radio propagation. This can

best be achieved in collaboration with neighbouring or other countries in similar geographic zones.

Thirdly, the need for an effective and efficient radio spectrum management cannot be over-emphasized. This embraces a flexible usage of the available radio spectrum. an adequate education of users of radio frequencies, and effective monitoring of spectrum usage.

Fourthly, if we are to take our place in the comity of nations in the world of modern radio, there must be adequate funding of radio research. The peculiarities of the equatorial ionosphere for radio communication are, for example, yet to be optimally harnessed.

Fifthly, there is a need for a regular exchange of ideas between practitioners and researchers in the many facets of radio.

Lastly, radio communication in its relation to space science, is in the forward ranks of modern technology. If we are to have real top-class radio communication therefore, there is no gain-saying the fact that we need a good grasp of the relevant technology. A situation in which we continue to consume all manner of hardware at great expense and sometimes against our own volition is no longer tenable. We must start somewhere. Why not with radio and electronic communication?

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