Analysis of the sunset equatorial ionosphere using absorption data

Nathaniel, E. U.[1], Thomas, J. E.[2] & Akpan, S. S.[3]

[1,2&3]*Department of Physics, Akwa Ibom State University, Ikot Akpaden, Mkpat Enin L. G. A., Nigeria.*

***Abstract*:** The absorption of a radio waves transmitted obliquely from a transmitter located at a distance about 110km in Cotonou $(lat.6^{0}22'N, Long.2^{0}26'E)$ from Lagos $(lat.6^{0}27'N, Long.3^{0}28'E)$ has been investigated. The absorption has been determined for a signal that was received on a tuned frequency of about 4.9MHz. The useful parameters for the determination of absorption have been obtained from manual on ionospheric absorption measurements. The results have been based on the post sunset data which have been calculated for different days.

***Keywords*- Ionosphere, electron density, absorption, collision frequency**

INTRODUCTION:

The solar ultraviolet (UV) light reaching the Earth's atmosphere ionizes a fraction of the neutral atmosphere (Belova et al., 1995; Mishin et al, 1995) At altitude above 80km, collisions are too rare to allow rapid recombination. This situation leads to the formation of a permanent ionized population referred to as the ionosphere (Baumjohann et al., 1996; Parks, 1991, Kivelson et al., 1995). The ionosphere is very useful in radio communication. For Earth, the ionosphere begins around 60km and extends to the magnetosphere. The equatorial ionosphere extends to about 3 to $4R_E$ (R_E= Earth's radius) (Parks, 1991). The ionosphere is a location of electric currents that produce the solar-controlled variation in the magnetic field measured at the surface of the Earth (Kivelson et al., 1995). This solar-controlled variation plays a serious role in radio wave propagation (Folkestad 1968; Rawer 1993; E. Nielson et al., 2007; I. Unal et al 2007). The electron density depends on the solar radiation which ionizes the Earth's atmosphere.

In a way to ascertain the parameters for the calculation that would produce result that could compare well with the observation, variation of the parameters such as electron density, collision frequency and the semi-thickness of layer is necessary. Although collision is infrequent, temperature of the ion and electron contributes to collision frequency used in the calculation of absorption. A parabolic variation of the electron density is assumed, which allows for the consideration of F_1 region of the ionosphere at this time of the day.

Due to the recombination process of the positive ions with the electrons, F_1 disappears towards sunset (Ionospheric bulletin) leaving the E and F_2 regions [Kelso, (1952); Thrane (1966); Thrane (1972)], but the height of reflection of the signal with the electron density defined by the signal frequency and the assumption of a parabolic variation of the electron density [Kelso (1950); Kelso (1952)] for a single layer allows for F_2 - region consideration.

Sunset and night field strength

The night time field strength E_n is used for signal calibration. A convenient sample may be obtained by measuring the maximum signal strength every three (3) minutes from three (3) hours after sunset (as given by Titheridge, 1966) until two (2) hours before sunrise at the ground (Chiptonkar, 1962). Extrapolation of the diurnal variation of the signal strength is rapid way of estimating the value of E_n. The procedure of extrapolation (Schwentek, 1976) can be made by drawing a pencil line through the maxima of the signal strength recorded during the post sunset time. This line represents the average variation of maximum signal strength. According to Schwentek, the extrapolation to the unattenuated night time value must be made with care because the duration of the transition interval depends on the frequency used and the distance between the transmitter and the receiver. The post sunset field strength E_d can also be determined very quickly by drawing the envelope through the peats of the signal strength.

Absorption calculation using observational data

The change in absorption from day to night (near sunset time) for a wave which is reflected in the same region of the ionosphere may be computed from the day time [near sunset time] and night time signal strengths, E_d and E_n respectively, and the corresponding half path length compensates for the effect of spatial attenuation.

For an angle of incidence α, the equivalent absorption for a frequency f_d at vertical incidence, $A(f_{d,}0)$ in dB is obtained from

$$A(f_d, 0) = A\,(f_d, \alpha).\cos\alpha \text{ -- } (1)$$

For a known post sunset field strength E_d, night time field strength E_n, post sunset half-path length S_d, and night time half-path length S_n,

$$A\left(f_{d,}0\right) = -Cos\alpha\ 20\log\left[\frac{\mathrm{E_d S_d}}{\mathrm{E_n S_n}}\right] \text{ --- } (2)$$

Therefore,

$$A\left(f_{d,}\alpha\right) = -20\log\left[\frac{\mathrm{E_d S_d}}{\mathrm{E_n S_n}}\right] \text{ -- } (3)$$

$Cos\alpha$ is determined using virtual height of reflection h and the distance d between the transmitter and the receiver.

$$Cos\alpha = \frac{h}{\left[h^2+\left({}^{d}/_{2}\right)^2\right]^{1/2}} \text{ -- } (4)$$

$$Cos\alpha = \frac{h}{s} \text{ --- } (5a)$$

$$h = scos\alpha \text{ --- } (5b)$$

Also, for known gains of the transmitting and relieving antennas G_t and G_r respectively, according to report UAG-57,

$$G_t \propto sin\alpha = \frac{d/2}{s} \text{--} (6)$$

$$G_r \propto cos\alpha = \frac{h}{s} \text{--} (7)$$

Therefore, absorption determination using oblique incidence is

$$A\left(f_{d,}\alpha\right) = -20\log\left[\frac{E_d S_d G_{tn} G_{rn}}{E_n S_n G_{td} G_{rd}}\right] \text{------------------------------------} (8a)$$

$$A\left(f_{d,}\alpha\right) = -20\log\left[\frac{E_d S_n G_{td} G_{rd}}{E_n S_d G_{tn} G_{rn}}\right] \text{------------------------------------} (8b)$$

G_{rn}- gain of receiver at night

G_{rd}- gain of receiver at around sunset time

G_{tn}-gain of transmitter at night

G_{td}- gain of transmitter at around sunset time

G_{td}=0.22dB, G_{rd}=0.98 dB, G_{tn}=0.16 dB, G_{rn}=0.86 dB

Observations and results

The observed night field strength E_n and post sunset field strength E_d were collected from the chart records [Shamsi, 1984; Rawer, 1967] near magnetic equator using oblique incidence. The transmitter located at a distance about 110km in Cotonou $(lat. 6^0 22'N, Long. 2^0 26'E)$ from Lagos $(lat. 6^0 27'N, Long. 3^0 28'E)$ sent signal that was received on a tuned frequency of about 4.9 MHz and was recorded on a chart sheet by a pen recorder continuously using A_3 method. The set-up or system of the receiver and recorder was calibrated and the absorption determined. Observational data were taken between 21/12/80 and 09/03/81. The average values of the night field strength were used for absorption calculation. For instance, the average diurnal value of the night field ranges between 40 and 200 µV within the period under investigation.

From the ionosphere bulletin, virtual height h' around sunset is about 250km, the slant height s is obtained as 256.0km for the distance d=110km (from Lagos to Cotonou). Angle of incidence α for these values is 12.4^0. Also, the virtual height for night is about 350km and the slant height is about 354.3km for angle of incidence $\alpha = 31.0^0$.

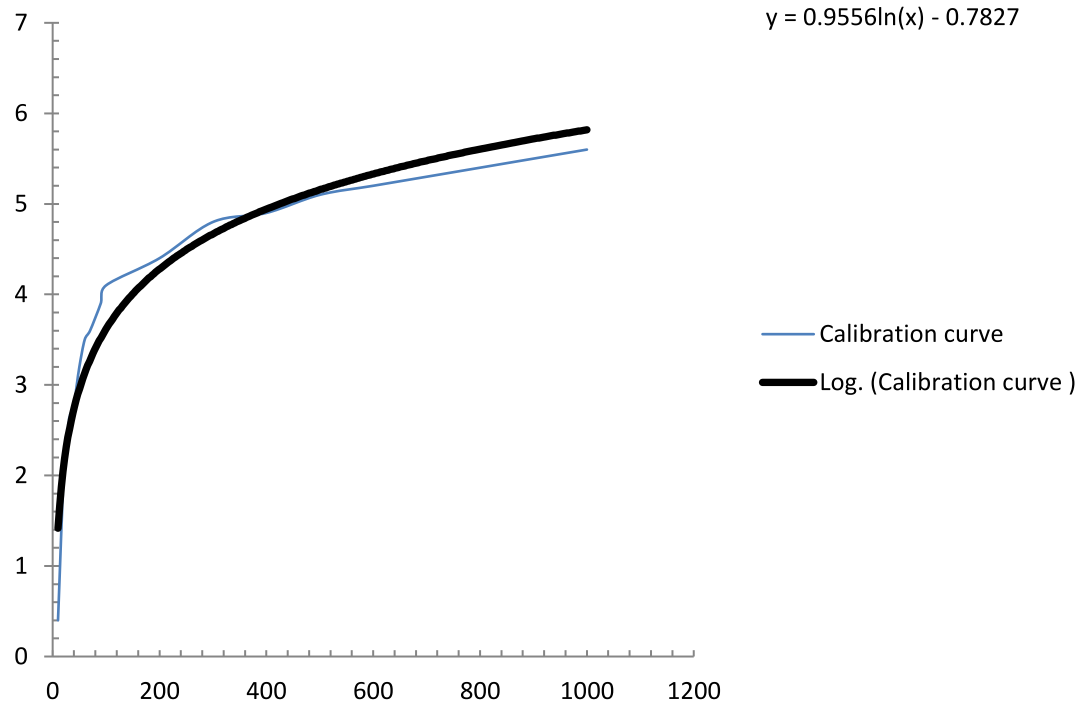
Therefore,

$$Absorption, L(dB) = 20log\left[1.992\frac{E_n}{E_d}\right] \text{------------------------------} (9a)$$

$$Absorption, L(dB) = 6.85 + 20log\left[\frac{E_n}{E_d}\right] \text{------------------------------} (9b)$$

Calibration curve for the system of receiver and recorder is shown figure 1 below. The thin blue line shows the actual calibration curve while the thick dark line shows the logarithm of the calibration curve. The equation of the curve is displayed at the right top corner of the figure 1. The vertical axis displays recorder's data (cm) while the horizontal axis displays the receiver's data (μV).

Figure 1 Calibration curve for January using frequency of 4.9Hz (Cotonou)



Using the sunset field strength and average night strength, the diurnal absorption (dB) is plotted against the sunset time (in minutes) as shown above.

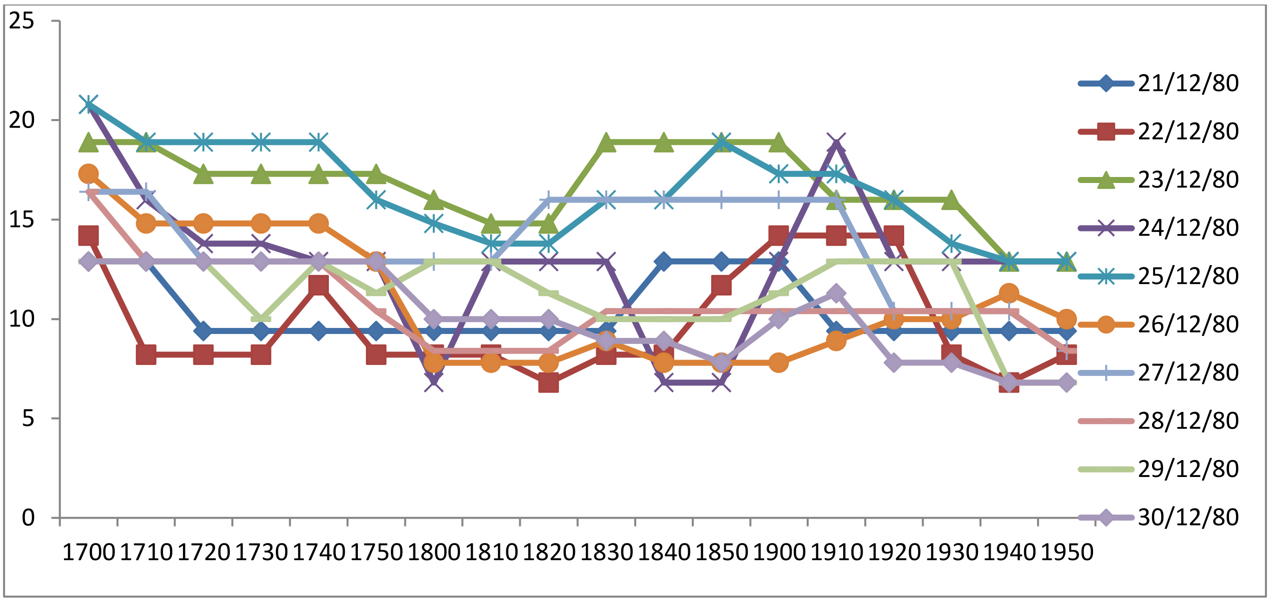


Figure 2 Graphical presentation of diurnal absorption values for ten (10) days. The vertical axis represents the absorption (dB) while the horizontal axis represents the time (min.)

Calculation of absorption based on electron density and collision frequency

The approximate electron density distribution for the ionosphere can be obtained with a known frequency (Checcacci et al 1964). Bracewell (1951) has shown that the height of reflection of 150 KHz radio waves is about 98km and the electron density required for reflection at this frequency is about 3.0 x $10^3/cm^3$. The ionospheric data, Bulletin 1968 has shown that radio waves is reflected at the height of about 350km with a frequency of 4.9MHz and requires the electron density of 2.9785 x $10^{11}/m^3$ for the reflection.
The absorption calculation equation is

$$L(dB) = \int Kds = \int_{h_0}^{h} N\nu dh$$

K = constant

N = electron density

ν = collision frequency

This equation is dependent on the variation of two parameters. These are N and ν.

The effective collision frequency, ν is defined in terms of the electron- neutral collision and the electron-ion collision. The electron neutral collision decreases with increase in height, h while the electron-ion collision increases with height. From the $\nu - h$ profile, at the height of

220km, the effective collision frequency is about 860Hz and at height range of 390-400km, it is about 2160Hz for electron-ion collision (Banks et al. 1973; Danilov et al 1970).

The electron density depends on the height

$$N = N_m \left[1 - \frac{y^2}{{y_m}^2}\right]$$

For instance, if y_m is varied N is generated. At the point of reflection of the radio wave, N attends it peak.

From the electron density equation above

Analysis of results of calculated absorption

At the maximum value of y i.e. y_m, y = 0, and N = N_m = 2.9785 x $10^{11}/m^3$. If $y \neq 0$, N varies. From the variation, N_m greater than 2.9785 x $10^{11}/m^3$ makes the value of the electron density very large. But N_m less than 2.9785 x $10^{11}/m^3$ makes N very small for a frequency of 4.9MHz.
Also, for y_m equals to 140km at the collision frequency υ equals to 860Hz and N_m equals to 2.9785 x $10^{11}/m^3$, the calculated absorption is 8.7dB. For y_m equals 150km at the same value of N_m and υ, the absorption increases to 9.2dB. For y_m equals to 130km, the absorption is 8.1dB

If y_m is kept at 140km, then N_m at 2.9785x$10^{11}/m^3$and υ is varied, say, υ is 1080Hz or 1.08 kHz, and then the absorption is 10.9dB. For υ equals to 1400Hz, the absorption is 14.2dB. If υ is 2160Hz, absorption is 21.8dB. Also, for y_m equal to 150km and N_m is also fixed at 2.9785 x $10^{11}/m^3$and υ is varied, say, υ = 1080Hz, the absorption is 11.6dB. Forυ = 1400Hz, the absorption is 15.0dB and for υ = 2160Hz, the absorption is 23.2dB. More also, for y_m equals to 130km and N_m still fixed at 2. 9785x$10^{11}/m^3$ and υ is 1080Hz, the absorption is 10.2dB. For υ =1400Hz, the absorption is 13.2dB. For υ =2160Hz, the absorption is 20.3dB.

Analysis of the result of the observed absorption

Within the period of sunset 1700-2100hrs, the daily observed absorptions were deduced from mean night field strength and the instantaneous day field strength. This aided the deduction of the average absorption across ten (10) days at every instance of time. For instance, a change in the night field strength E_n will change the absorption value. Example; on the 21/12/80, E_n mean night field strength, E_n of 40μV with a mean day field strength E_d of 30μV at 1700hrs led to absorption of 12.9dB. Also, E_n = 60μV, E_d = 30μV, absorption is 16.4dB at 1700hrs. E_n =200μV, E_d = 30μV at 1700hrs, the absorption is 20.8dB. Also, when E_d is 60μV, E_n = 40μV at 1800hrs, the absorption is 9.4dB. E_n = 60μV, absorption is 12.9dB. E_n = 200μV, absorption is 14.8dB.

Discussion

As the day gradually opens way for the night, the base of the ionosphere gradually moves up till it gets to 220km. the D and E regions have completely disappeared at this height. The electron-ion collision frequency also increases with height. The number of electron within a given range of height depends on the difference between the base and the peak of height (h_m – h) or y_m which is called the semi-thickness. At the peak of 350km (hm) and base of 220km (h), y_m = 130km. This is the optimum value.

Between 12/12/80 and 30/12/80, the mean absorption data is presented below;

Time (hr)	Absorption, dB
1700	16.35
1710	14.48
1720	13.40
1730	13.40
1740	13.66
1750	12.42
1800	10.72
1810	11.11
1820	10.81
1830	11.65
1840	11.28
1850	11.81
1900	12.86
1910	13.22
1920	12.00
1930	11.18
1940	10.06
1950	9.67

The semi thickness $y_m = h_m – h$, helps in the determination of the election density. The signal frequency determines the maximum electron density at the point of reflection of the wave. For instance, a frequency of 4.9MHz is reflected at hm = 350km where the electron density is $2.9785 \times 10^{11}/m^3$. Within the sunset period, the calculated absorption at effective election-ion collision frequency of 1200Hz allows absorption of 12.9dB which corresponds to then mean observed absorption of 12.86dB at 1900hrs across ten (10) days. Within this semi-thickness of 130km, calculated absorption for effective collision of 860Hz is 8.1dB which does not correspond to the observed absorption. Also, the calculated absorption at collision frequency of 1080 – 1100Hz ranges from 10.2-11.81dB which corresponds to the observed absorption between 1800-1850hrs and 1930-1950hrs i.e. 9.67-13.22dB. The calculated absorption for ν = 1400Hz is 13.2dB which corresponds to the observed absorption that ranges from 13.22dB at 1910hrs.

Above 1400Hz of collision frequency to 2160Hz, the calculated absorption ranges from above 13.2dB to 20.3dB which approximately corresponds to the observed absorption between 1700hrs to 1740hrs of 13.66-16.35dB. But the ν = 2160Hz has absorption that does not correspond since this is the frequency the height of 350km. At the later time within the sunset period the absorption values gradually decreases. The consequence of this is that lower frequency signals can be received. From the comparison derived from both the calculated and observed absorption, the effective collision frequency of 2160Hz takes place within 390-400km which is height ranger higher than the peak of 350km where the signal of 4.9MHz is reflected.

Conclusion

The calculated absorption consistent with the observation are mainly based on the variation of the electron density, N and the effective collision frequency ν in the absorption calculation equation

$L(dB) = R\int_{h_0}^{h} N\nu dh$ R is a constant

Since the electron density is maximum, N_m in the electron density equation

$$N = N_m\left[1 - \frac{y^2}{{y_m}^2}\right]$$

is optimum at 2.9785 x 10^{11}electrons/m^3 and it is calculated that an increase brings about a very large absorption result while a decrease brings about a very small absorption result. This leads to the conclusion that N is solely based on y_m variation. The desired absorption to model to the ionosphere at this time is done with the variation of the collision frequency ν, the $\nu - h$ data for the height range of 220km to 400km varies from 860Hz. Where the peak electron density is fixed, the variation in absorption can be traced to the $\nu - h$ profile.

With the optimal value of y_m at 130km and N_m at 2.9785 x 10^{11}/m^3, the calculated absorption is based on the variation of the effective collision frequency, υ. The effective collision frequency is varied between the base of the ionosphere at this time (220km) to the true height of reflection of the signal used i.e. 4.9MHz (350km). The calculated absorption value that corresponds to the observed absorption value is defined in terms of the electron density and the effective collision frequency. The calculated absorption validates the observed absorption deduced from their experimental work

It is concluded here also that the observed absorption value within the sunset period starts to decrease from the sunset starting point of 1700hrs, then remains fairly constant between 1800hrs and 1950hrs as seen from the average observed absorption values taken across ten (10) days. After about (2) two hours of constant absorption, the absorption value starts decreasing into the sunset and night (figure2). This conclusion implies that the transmitted signals can be seriously absorbed in the day while the absorption starts decreasing towards sunset, and then remains constant for about two (2) hours before finally decreasing in value in the night.

References

Titheridge, J. E. Continuous records of the total electron content of the ionosphere. J. of Atmos. and Terr. Phys. 1966; 28: 1135-1150.

Baumjohann, W. and Treumann, R. A. Basic space Plasma Physics. Imperial College Press, London, 1996.

Kivelson, M. G. and Russell, C. T. Introduction to Space Physics. Cambridge University Press, 1995.

Parks, G. K. Physics of Space Plasmas: An introduction. Addison-Wesley Publishing Company, The Advanced Book Program, 350 Bridge Parkway, Redwood City, CA 94065, 1991.

Folkestad, K. Ionospheric radio communication. Plenum Press, New York, 1968.

Rawer, K. Manual on Ionospheric absorption measurements. J. of Atmos. and Terr. Phys. 25. 1967.

Rawer, K. Wave propagation in the ionosphere; Developments in Electromagnetic theory and applications. Kluwer Academic Publishers. Vol. 5.1993.

Banks, P. M. and Kockarts, G. Aeronomy, Part A. Academic Press Inc. LCCC, 1973.

Danilov, A. D. Chemistry of the Ionosphere. Plenum Press, New York (London), 1970.

Kelso, J. M. The calculation of ionospheric electron density distributions. J. of Atmos. and Terr. Phys., 1950; 10: 103-109.

Kelso, J. M. A procedure for the determination of the vertical distribution of the electron in the ionosphere. J. Geophy. Res., 1952; 57: 357-367.

Thrane, E. V. & Piggot, W. R.. The electron densities in the E and D regions above Kjeller. J. of Atmos. and Terr. Phys. 1966; 28: 467-479.

Thrane, E. V. Information on the D and E region electron density profiles. Radio Science. 1972; 7(1): 143-145.

Mishin, E. V. and Atamaniuk, B. Radio wave turbulent absorption due to electron injection in the ionosphere. J. of Atmos. and Terr. Phys. 1995; 57: 193-199.

Belova, E. G., Pashin, A. B. a Lyatsky, W. B. Passage of a powerful HF radio wave through the lower ionosphere as a function of initial electron density profiles. J. of Atmos. and Terr. Phys.1995; 37: 265-272.

Unal, I., Ozcan, O. and Canyilmaz, M. Ionospheric absorption of HF radio wave in vertical propagation. Iranian journal of science. Transaction A, 2007; 31(4).

Nielsen, E., Morgan, D. D., Kirchner, D. L., Plaut, J. and Picardi, G. Absorption and reflection of radio wave in the Martian ionosphere. Planetary and space science. 2007; 55: 864-870.

Ionospheric data, Bulletin 1968. Ibadan, Nigeria.

Chiptonkar, M. W. and Karekar, R. N. The unrise and sunset effects on the level of atmospheric activity on the 27 KC/s band. J. of Atmos. and Terr. Phys. 1962; 25: 23-34.

Schwentek, H. (1976). Oblique field strengthobservations on frequencies above 2 MHz. Manual on ionospheric absorption measurements. Report UAG-57.

Shamsi, (1984). Oblique incidence ionospheric absorption near magnetic equator. University of Lagos Press. Lagos.