Analysis of the sunset equatorial ionosphere using absorption data

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Abstract: The absorption of a radio waves transmitted obliquely from a transmitter located at a distance about 110km in Cotonou (lat. 6°22'N, Long. 2°26'E) from Lagos (lat. 6°27'N, Long. 3°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 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 4RE (RE= 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 F₁ region of the ionosphere at this time of the day.

Due to the recombination process of the positive ions with the electrons, F₁ disappears towards sunset (Ionospheric bulletin) leaving the E and F₂ 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 F₂ - 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 a 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 peaks 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 $\alpha$, the equivalent absorption for a frequency $f_d$ at vertical incidence, $A(f_d, 0)$ in dB is obtained from

$$A(f_d, 0) = A(f_d, \alpha). \cos \alpha$$

(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 $S_n$,

$$A(f_d, 0) = -\cos \alpha 20 \log \left[ \frac{E_d S_d}{E_n S_n} \right]$$

(2)

Therefore,

$$A(f_d, \alpha) = -20 \log \left[ \frac{E_d S_d}{E_n S_n} \right]$$

(3)

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

$$\cos \alpha = \frac{h}{\sqrt{h^2 + (d/2)^2}}$$

(4)

$$\cos \alpha = \frac{h}{s}$$

(5a)

$$h = s \cos \alpha$$

(5b)
Also, for known gains of the transmitting and relieving antennas $G_t$ and $G_r$ respectively, according to report UAG-57,

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

$$G_r \propto \cos \alpha = \frac{h}{s}$$  \hspace{2cm} (7)

Therefore, absorption determination using oblique incidence is

$$A \left( f_d, \alpha \right) = -20 \log \left[ \frac{E_dS_dG_{tn}G_{rn}}{E_nS_nG_{td}G_{rd}} \right]$$  \hspace{2cm} (8a)

$$A \left( f_d, \alpha \right) = -20 \log \left[ \frac{E_dS_dG_{td}G_{rd}}{E_nS_dG_{tn}G_{rn}} \right]$$  \hspace{2cm} (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

$G_{dt}=0.22\,\text{dB}$, $G_{rd}=0.98\,\text{dB}$, $G_{tn}=0.16\,\text{dB}$, $G_{tm}=0.86\,\text{dB}$

**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 ($lat.\,6^022'N, Long.\,2^026'E$) from Lagos ($lat.\,6^027'N, Long.\,3^028'E$) 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 $\mu V$ 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 $d=110$km (from Lagos to Cotonou). Angle of incidence $\alpha$ 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,

$$Absorption, L(dB) = 20 \log \left[ 1.992 \frac{E_n}{E_d} \right]$$  \hspace{2cm} (9a)

$$Absorption, L(dB) = 6.85 + 20 \log \left[ \frac{E_n}{E_d} \right]$$  \hspace{2cm} (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.
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 $3.0 \times 10^3$/$cm^3$. 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 $2.9785 \times 10^{11}$/m$^3$ for the reflection.

The absorption calculation equation is

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

$K = \text{constant}$

$N = \text{electron density}$

$\nu = \text{collision frequency}$

This equation is dependent on the variation of two parameters. These are $N$ and $\nu$.

The effective collision frequency, $\nu$ 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 \( N = N_m = 2.9785 \times 10^{11}/m^3 \). If \( y \neq 0 \), \( N \) varies. From the variation, \( N_m \) greater than \( 2.9785 \times 10^{11}/m^3 \) makes the value of the electron density very large. But \( N_m \) less than \( 2.9785 \times 10^{11}/m^3 \) makes \( N \) very small for a frequency of 4.9MHz.

Also, for \( y_m \) equals to 140km at the collision frequency \( v \) equals to 860Hz and \( N_m \) equals to \( 2.9785 \times 10^{11}/m^3 \), the calculated absorption is 8.7dB. For \( y_m \) equals 150km at the same value of \( N_m \) and \( v \), 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 \( 2.9785\times10^{11}/m^3 \) and \( v \) is varied, say, \( v \) is 1080Hz or 1.08 kHz, and then the absorption is 10.9dB. For \( v \) equals to 1400Hz, the absorption is 14.2dB. If \( v \) is 2160Hz, absorption is 21.8dB. Also, for \( y_m \) equal to 150km and \( N_m \) is also fixed at \( 2.9785 \times 10^{11}/m^3 \) and \( v \) is varied, say, \( v \) = 1080Hz, the absorption is 11.6dB. For \( v \) = 1400Hz, the absorption is 15.0dB and for \( v \) = 2160Hz, the absorption is 23.2dB. More also, for \( y_m \) equals to 130km and \( N_m \) still fixed at \( 2.9785\times10^{11}/m^3 \) and \( v \) is 1080Hz, the absorption is 10.2dB. For \( v \) = 1400Hz, the absorption is 13.2dB. For \( v \) = 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 40\( \mu \)V with a mean day field strength \( E_d \) of 30\( \mu \)V at 1700hrs led to absorption of 12.9dB. Also, \( E_n = 60\mu V, E_d = 30\mu V \), absorption is 16.4dB at 1700hrs. \( E_n = 200\mu V, E_d = 30\mu V \) at 1700hrs, the absorption is 20.8dB. Also, when \( E_d = 60\mu V, E_n = 40\mu V \) at 1800hrs, the absorption is 9.4dB. \( E_n = 60\mu V \), absorption is 12.9dB. \( E_n = 200\mu V \), 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 \((h_m)\) and base of 220km \((h)\), \(y_m = 130\)km. This is the optimum value.

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

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

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 \(h_m = 350\)km where the electron density is \(2.9785 \times 10^{11} / m^3\). Within the sunset period, the calculated absorption at effective electron-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 \(\nu = 1400\)Hz 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

\[ L(dB) = R \int_{h_0}^{h} N \nu dh \quad R \text{ is a constant} \]

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 \( 2.9785 \times 10^{11} \text{electrons/m}^3 \) 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 \( ν - h \) 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 \( ν - h \) profile.

With the optimal value of \( y_m \) at 130km and \( N_m \) at \( 2.9785 \times 10^{11}/\text{m}^3 \), the calculated absorption is based on the variation of the effective collision frequency, \( \nu \). 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**


