STUDY OF GASEOUS ATTENUATION AT TROPICAL LOCATIONS

***D.A Adenugba and L.B Kolawole**

Department of Physics, Federal University of Technology, Akure,
P.M.B 704, Akure, Ondo State. Nigeria.
E-mail: atereade@hotmail.com

(Submitted: 10 February, 2006; Accepted: 24 May, 2006)

Abstract

Oxygen and Water Vapour are the principal absorbers of transmitted radio signals in the troposphere. This paper evaluates the specific gaseous attenuation due to Oxygen and Water Vapour at four tropical sites in the frequency range of 10-350 GHz using Liebe model. The isolated resonant absorption line of Oxygen was found to be at 118 GHz, together with series of absorption spectra lines between 54-66GHz, the peak being at 60 GHz. The spectra lines of Water Vapour appear at 22, 184 and 326GHz. The specific attenuation exhibits both seasonal and geographical variations. It is generally higher during wet season than dry season; Kano (3.12°N, 8.32°E), an inland site, has the least specific attenuation, while Lagos (6.32°N, 3.21°E), a coastal station, has the highest values. The implications of the results for microwaves communication links are also discussed.

Key words: *Oxgyen, water vapour, specific attenuation, microwaves absorption*

Introduction

The specific absorption due to atmospheric gases is significant in that it determines transmitted power and antenna gain. Although specific absorption can be neglected below 10 GHz, it becomes relevant with increasing frequency above 10 GHz(Ajayi et al., 1962). At centimetre and millimetre wavelengths, oxygen and water vapour are the two principal atmospheric gases responsible for molecular absorption. Unlike polar molecules, non-polar molecules such as oxygen molecules, do not exhibit resonant absorption due to electric dipole resonance. However, because of its permanent magnetic dipole moment, it can interact with electromagnetic radiation. This interaction results in resonant absorption at certain frequencies. Water vapour molecule, on the other hand, is a polar molecule, which has electric dipole moment that interacts with incident radiation to cause absorption at critical frequencies (Barbaliscia et al., 1994a; Barbaliscia et al., 1994; Brussard et al., 1995 and ITU-R, 1990). Studies on gaseous attenuation in Nigeria are very few and narrow in coverage. This situation is probably due to lack of modern equipment, funds and insufficient atmospheric scientists in the nation to probe into this vital atmospheric parameter of importance to system engineers. If computer software packages on gaseous attenuation prediction can easily be obtained for use, perhaps much more could have been done than hitherto procured.

Up to now there is no gaseous attenuation measurement in the country. Gaseous attenuation predictions had been done using models developed with temperate data (Ajayi, 1996 and Adedugba, 2000).To produce a tropical based model, gaseous attenuation measurements are needed. In the absence of measured data, we still have to rely on temperate-based prediction models for attenuation evaluation in this part of the world. Thus the computations of gaseous absorption of

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**Corresponding author*

radio wave signals presented in this paper makes use of Liebe model to provide data and information on attenuation due to gases at four sites in Nigeria.

Theory

The interaction of radiation with the atmospheric medium causes absorption and scattering of signal. A plane wave propagating the distance, x can be described in phase and amplitude by

$$E(x) = E_o \exp[-j(w/c)x.n] \qquad (1.1)$$

where E_o is the initial field strength, c is the speed of light in vacuum, the angular frequency,

$\omega = 2\pi f$ and $j = -1$

The complex refractive index, n is related to complex refractivity, N by (ITU-R, 1990; Liebe, 1983 and Liebe, 1989)

$$N(f) = (n-1)10^6 \text{ ppm} \qquad (1.2)$$

The refractivity is modeled on easy-to -measure parameters of temperature, pressure and water vapour partial pressure by

$$N = N_o + N'(f) - jN''(f) \qquad (1.3)$$

The frequency -independent part, No is given by (Liebe, 1983 and 1989)

$$N_o = (2.589p + 41.6et + 2.39e)t \qquad (1.4)$$

The real frequency dependent part $N'(f)$ is the dispersion part which causes phase delay, while the imaginary part $N''(f)$ causes absorption . The specific gaseous attenuation is expressed by

$$\propto_c = 0.1820fN''(f) \quad \text{dBkm} \qquad (1.5)$$

The frequency dependence of the absorptive term is

$$N''(f) = \sum_i {}_i(SF)_i + N_D''(f) + N_W''(f) \qquad (1.6)$$

where the summation is over all absorption lines, S_i is the strength of the ith line, F_i is the complex line shape factor; $N_D''(f)$ and $N_W''(f)$ are dry and wet continuum spectra. The line shape factor for both oxygen and water vapour is given by

$$F_i = \frac{f}{\upsilon_o}\left\{\frac{\gamma_i - (\upsilon_o - f)I_1}{(\upsilon_o - f)^2 + \gamma_i^2} + \frac{\gamma_i - (\upsilon_o + f)I_1}{(\upsilon_o + f)^2 + \gamma_i^2}\right\} \qquad (1.7)$$

where υ_o is the resonance frequency, γ_i is the pressure broadened line width in GHz and I_i is the pressure-induced interference coefficient due to oxygen lines(Liebe, 1983). The oxygen spectra line parameters are expressed in terms of six spectroscopic coefficients, a_1-a_6 and the line centre frequencies by

$$S_i = a_1 p t^3 \exp[a_2(1-t)]\, 10^{-6} \qquad (1.8)$$

$$\gamma_i = a_3(p t^{(0.8-a4)} + 1.1et)10^{-3} \qquad (1.9)$$

$$I_i = (a_{5+} a_6 t)\, 10^{-3} p t^{0.8} \qquad (1.10)$$

where the inverse temperature, t (°C) is related to the absolute temperature, T(K) by

$$t = 300/T \qquad (1.11)$$

p is the dry air pressure, e is the water vapour partial pressure both in hPa.

The corresponding line parameters for water vapour, given in terms of six spectroscopic coefficients $b_{1-}b_6$ are

$$S_i = b_i e t^{3.5} \exp[b_2(1-t)] \qquad (1.12)$$

$$\gamma_i = b_3(p t^{b4} + b_5 e t^{b6)}10^{-3} \qquad (1.13)$$

$$I_i = 0 \qquad (1.14)$$

The dry air continuum, $N_D''(f)$ arises from Debye spectrum of oxygen below 10 GHz and a pressure-induced nitrogen absorption above 100 Hz and is expressed by

$$N_D''(f) = \frac{S_d f}{\gamma_o\left[1 + \left(\frac{f}{\gamma_o}\right)^2\right]} + a_p f p^2 t^{3.5} \qquad (1.15)$$

with the Debye strength, S_d and width, γ_o given by

$$S_d = 6.14\, 10^{-4} p t^2 \qquad (1.16)$$

$$\gamma_o = 5.6\, 10^{-3} (p + 1.1e) t \qquad (1.17)$$

The nitrogen coefficient, $a_p = 1.40(1 - 1.2 (10^{-5} f^{1.5}) 10^{-10}$ (1.18)

The wet continuum, $N_W''(f)$ is expressed by

$$N_W''(f) = 1.18\ X 10^{-8} (p + 30.3 e^{t6}) f e t^3 + 2.3\ x\ (10^{-10} p e^{1.1} t^2 f^{1.5} \qquad (1.19)$$

and it is included to account for the excess water vapour measured above that predicted [5,8,9].

Method

The data base consists of resonance frequencies, ν_o, permanent spectroscopic coefficients: 44 for oxygen, a_1-a_6 and 30 for water vapour, b_1-b_6, frequency between 10 and 350GHz and monthly mean surface meteorological parameters of pressure, temperature and relative humidity obtained from four Nigerian meteorological stations. These stations are Lagos (Lat. 06° 32'N, Long. 03° 21'E), Akure (FUTA) (Lat. 07° 17'N, Long. 05° 14'E) which are in the Southern part of Nigeria; Kano (Lat. 03° 12'N, Long. 08° 32'E) and Minna (Lat. 09° 57'N, Long. 06° 32'E) are situated in the Northern part. The data employed are all for 1200hr GMT and for a five-year period. The periods, however, are not uniform for the stations as Tables1-4 show due to non-availability of data.

The data are grouped into two: dry and wet, along the two principal seasons in Nigeria. The peak dry and wet seasons respectively are January and July. This grouping permits the comparison of the effect of attenuation during dry season with that of wet season. To plot graphs, a flexible computer package- ORIGIN- was employed.

Results and Discussion

Tables' 1-4 show typical computed specific gaseous attenuation values for all the sites. The attenuation is observed to be higher in wet season than in the dry season. The observed high values can be accounted for by high relative humidity and pressure, and low temperature that characterized the wet season. Locational variations indicated that Kano, a hither land, has the least value, while a coastal station, Lagos has the highest values.

Table 1: A typical computed attenuation for oxygen and water vapour for dry and wet seasons at AkureT

Oxygen

FREQ (GHz)	60		118		22		184		326	
YEAR	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1981	12.26	13.36	0.93	1.01	.30	.44	44.96	68.86	61.67	94.76
1982	13.08	13.58	0.99	1.02	18	.46	27.51	71.19	36.54	97.86
1983	12.83	13.52	0.97	1.02	.23	.44	34.77	69.25	46.74	95.10
1975	13.24	13.68	1.01	1.03	.15	.42	23.46	66.19	30.96	90.37
1990	12.87	13.52	0.97	1.02	.21	.43	32.85	67.63	44.05	92.71

Table 2: A typical computed attenuation for oxygen and water vapour for dry and wet seasons at Minna

FREQ (GHz)	60		118		22		184		326	
YEAR	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1990	13.51	14.05	1.01	1.00	.45	.40	70.24	62.42	96.96	85.88
1991	13.88	14.12	1.04	1.06	.43	.36	66.70	57.17	91.63	77.49
1992	14.19	14.25	1.07	1.07	14	.33	22.05	53.37	28.83	71.90
1993	13.62	13.98	1.02	1.05	.22	.41	34.16	64.11	45.64	87.70
1995	14.18	14.00	1.07	1.05	.15	.41	24.34	64.19	31.89	87.80

The graphical illustrations of the results are given in figures1-2.The peaks of these graphs indicate the zenith of the resonant absorptions. Water vapour shows the weakest resonant absorption line at 22GHz with a dispersion values between 0.11-0.48dB/km and 0.41-50.0dB/km for dry and wet seasons respectively. Also, water vapour presents a weaker spectrum at 184GHz which correspond to attenuation of about 17-73dB/km for dry season and 64-76dB/km for wet season. The strongest line at 326GHz is approximately between 23-94dB/km and 88-106dB/km for dry and wet seasons respectively. Water vapour spectrum had been reported at 325,183.3 and 22.3GHz which correspond to 40dB/km, 50dB/km, and to less than 0.2dB/km in that order (Barbaliscia et al., 1994a; Brussard et al., 1995 and Westwater et al., 1994).

The absorption of Oxygen up to 52 GHz is small. This is due to the constant concentration of Oxygen in the atmosphere. This observation is in agreement with that obtained for the Italian climate (Barbaliscia et al., 1994a and Brussard et al., 1995).There is a maximum Oxygen

Table 3: A typical computed attenuation for oxygen and water vapour for dry and wet seasons at Lagos

FREQ (GHz)	60		118		22		184		326	
YEAR	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1966	13.51	13.84	1.01	1.03	.43	.46	65.60	71.57	90.76	99.24
1968	13.58	13.88	1.01	1.03	.43	.46	66.39	71.61	91.86	99.29
1969	13.52	13.42	1.01	1.00	.44	.50	67.12	75.93	93.00	106.30
1990	13.41	13.88	1.00	1.03	.48	44	73.37	67.98	102.71	93.93
1991	13.45	13.84	1.00	1.03	.43	.44	66.76	68.80	92.64	95.25

Table 4: A typical computed attenuation for oxygen and water vapour for dry and wet seasons at Kano

	OXYGEN				WATER VAPOUR					
FREQ (GHz)	60		118		22		184		326	
YEAR	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1981	13.09	13.09	1.01	1.00	.11	.41	17.43	64.45	22.71	87.68
1982	13.08	13.36	0.99	1.01	.38	.44	27.51	68.86	36.54	94.76
1983	12.83	13.52	0.97	1.02	.23	.44	34.77	69.25	40.74	95.10
1985	13.10	12.82	1.01	0.98	.15	.39	23.41	60.71	30.63	82.67
1989	12.76	12.82	0.98	0.98	.29	.42	45.20	65.00	60.66	88.81

absorption at 60 GHz and this corresponds to approximately 13-14dB/km. The series of Oxygen resonant absorption lines which occur between 54GHz and 66GHz can guarantee frequency reuse beyond a few kilometers without the risk of co-channel interference. An isolated spectral Oxygen line was observed at 118GHz which agrees with other researchers' results (McEwam, 1989; Watson, 1989 and Westwater et al., 1994). At 50GHz the attenuation is approximately 0.3dB/km.This value is smaller than that obtained for the Italian climate (Barbaliscia et al., 1994d) as a result of the differences in climatic conditions on which Oxygen attenuation depends.

We have computed the specific gaseous attenuation using Liebe semi-empirical model. Oxygen has an isolated absorption line at 118GHz together with series of absorption spectral lines between 54-66GHz. On the other hand, water vapour has three resonant absorption lines at 22,184 and 326 GHz. Attenuation is found to be higher during wet season than dry season. In planning and predicting transmission and reception of radio wave signals this work will prove invaluable for the sites considered. For a complete

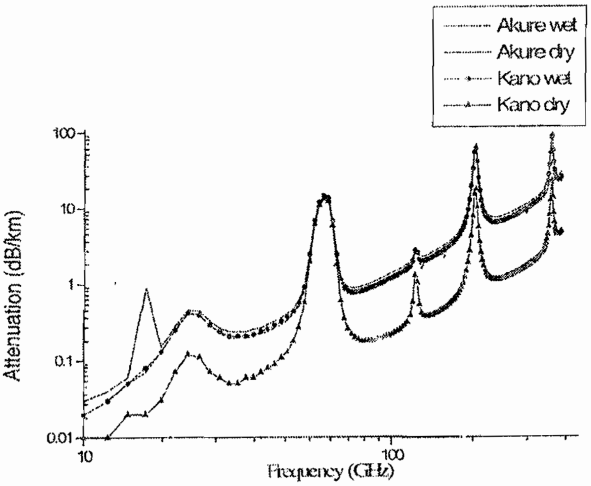

Fig. 1: Specific attenuation due to moist air for dry and wet seasons at Akure and Kano sites

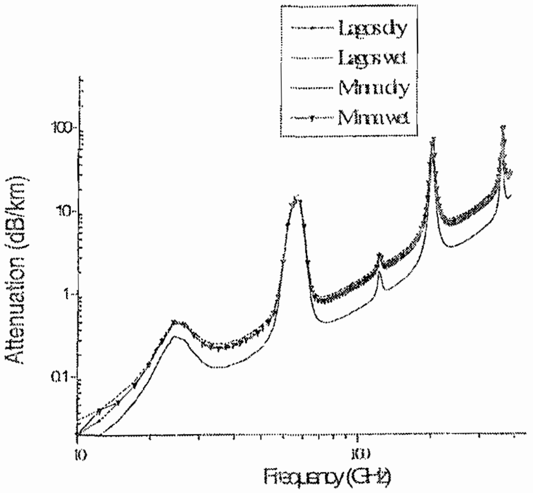

Fig2: Specific attenuation due to moist air for dry and wet seasons at Lagos and Minna sites

characterization of atmospheric gaseous attenuation in Nigeria, however, there is need to extend this work to other locations in the country and embark on gaseous attenuation measurement. Besides, user-friendly interactive computer software is needed for gaseous attenuation evaluation.

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