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GROUND ELECTRICAL CONDUCTIVITY FOR MEDIUM WAVE LINK DESIGN AT ILORIN, NIGERIA

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ABSTRACT.

Ground electrical properties remain a useful tool for most applications in engineering and communication, therefore, reliability and precision is highly required in their determination. Ground electrical conductivity as a function of signal frequency has been determined at Ilorin during the dry and the wet seasons. The study revealed that the mean conductivity during the wet season is higher than that of dry season. The values range from 3.5mS/m - 5.0mS/m for the dry season and 4.6mS/m - 6.3mS/m for the wet season. The variation of skin depth with signal frequency was also investigated. Correlation coefficients ranging from 0.8598 to 0.9834 were obtained between the signal frequency and the measured ground electrical conductivity at different hours of the day for both seasons using the statistical analysis toolpack of Microsoft Excel 5.0.

Keywords: Ground, Electrical, Conductivity, Season, Frequency

INTRODUCTION.

In view of the numerous problems often encountered in the medium wave broadcast band, the need to study some ground parameter normally associated with the mode of propagation is highly essential. In the MF broadcast band, the mode of propagation is by ground wave. As the electromagnetic wave travels along its path, the signal strength diminishes. This attenuation of signal is largely due to the effect of some ground parameters such as dielectric constant, relative conductivity. It has been found that the signal strength above the ground in the horizontal and vertical direction increases with ground electrical conductivity (Grob, 1982). For effective planning and management of medium wave broadcast station therefore, there is the need to have adequate knowledge of ground electrical conductivity of the expected coverage area. Ground electrical parameters needed to be taken into account in the installation of antenna systems for the purpose of signal transmission. The earth can be seen as non-magnetic and so a free space permeability can be assumed. For a homogeneous earth over which the electromagnetic wave propagates, permeability of the ground and the ground electrical the electrical conductivity instead of the dielectric constant predominates. Ground electrical conductivity is expected to vary with time since its value depends substantially on the environment of the study area, the types of underlying rocks, vegetation and moisture content. (ITU -R, Rec. 527-1, 1986). Electrical conductivity at the upper layer of the ground is by electrolytic ion conduction (Noritomi. 1961), ground moisture content however, play a significant role in the electrical conductivity of the ground. Wet ground therefore, is expected to increase signal pick up along its line of propagation. Radio frequency signal generates radio frequency current within the antenna mast during transmission.In order to protect antenna systems from damage that could result during lightning discharge, the ground in which the antenna mast is situated must be of good electrical conductivity. During severe thunderstorm, the heat build up on the mast will damage it unless the ground is properly screened. This radio frequency current tends to impede signal radiative power of the antenna thereby leading to collapse of signal. Data from direct measurement of ground electrical conductivity for medium wave radio broadcast planning in Nigeria has been very scarce. Field strength measurement of MF was reported by Ajayi and Owolabi (1975), and ECCU (1979) for some parts of Nigeria. The reports derived ground conductivity from propagation curves of the measured field strength with values ranging from 1 - 10 msm^{-1}. ITU-R Report 879-1(1986) and ITU-R Report 845-2(1995) also reported a range of 0.1 - 30 msm^{-1} and 2 - 10 msm^{-1} respectively. The objective of this study therefore, is to investigate the variation of ground electrical conductivity in respect of the signal frequency. Good knowledge of ground electrical conductivity is required for good ground screening system to maximize antenna efficiency (ITU-R, Report 879-1,1986).

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RELEVANT THEORY OF ELECTROMAGNETIC WAVE PROPAGATION

Maxwell's equations relate the electromotive force, to the time derivative of the magnetic displacement, and magnetomotive force to the total current around a loop by

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad (1)$$

$$\nabla \times B = \quad - \quad - \frac{\varepsilon_r}{c^2}\frac{\partial E}{\partial t} \qquad (2)$$

where μ_0 is the permeability of free space, ε_r is the permitivity of the medium and σ is the conductivity of the medium.

Since both electric(E) and magnetic(B) fields are radiated into space as electromagnetic waves, the wave equation can be derived by taking the curl of equation (1).

$$\text{curl curl } E = -\frac{\partial(\text{curl}B)}{\partial t}$$

$$= -\mu_0 \sigma E - \frac{\varepsilon_r}{c^2}\frac{\partial^2 E}{\partial t^2}$$

but Curl Curl E = $-\nabla^2 E$

$$\nabla^2 E = \mu_0 \sigma \frac{\partial E}{\partial t} + \frac{\varepsilon_r}{c^2}\frac{\partial^2 E}{\partial t^2} \qquad (3)$$

Considering a plane wave propagation through a medium

$$E = E_0 e^{i(kx-\omega t)} \qquad (4)$$

where ω is a measure of the frequency of the wave.

Substituting equation (4) into equation (3) we have the wave number, k to be

$$k^2 = \frac{\omega^2 \varepsilon_r}{c^2} + i\mu_0\sigma\omega \qquad (5)$$

Equation (5) suggest a complex medium such as the earth surface.

MATHERIALS AND METHOD

In the determination of ground conductivity, signal generator was employed as the current source in order to investigate frequency characteristics of ground electrical conductivity. The method of continuous profiling with constant electrode spacing of 0.833m known as the Wenner array vertical electrical sounding (VES) was used (see fig. 1). The electrode spacing was one-third of the separation between the two outer current electrodes. Ground frequency characteristics was investigated at 9.00am, 12.00noon, 3.00pm and 6.00pm for 40 cm depth during the dry season and the wet season as shown in Tables 1 and 2 respectively.

The theoretical determination of ground electrical conductivity using this method was made possible in view of the symmetry of current flow resulting in uniform current density through a sphere of radius r as shown in fig. 2. If the ground is assumed to be a piece of conductor of length L and cross sectional area A, the resistance is related to the measured current, I and potential differences, V by

$$\rho = \frac{RA}{L} = \frac{\Delta V}{I}\frac{A}{L} \qquad (6)$$

where R is the resistance in ohms.

For an infinitesimal change in conductor size

$$\rho = \frac{R\Delta A}{L} = \frac{\Delta V}{I}\frac{\Delta A}{L} \qquad (7)$$

For the Wenner Array method, the potential difference between the potential electrodes B & C for semi-infinite earth of unknown resistivity ρ, is expressed by

$$\Delta V = V_B - V_C = \frac{I\rho k}{2\pi} \qquad (8)$$

The geometric factor k is given by

$$= \left(\frac{1}{AC} - \frac{1}{BC} - \frac{1}{AD} + \frac{1}{BD}\right) \qquad (9)$$

$\rho = \frac{2\pi}{I} a \Delta V$ is the apparent resistivity which is independent of electrode positions, and 'a' is the electrode spacing. For a uniform apparent resistivity within the subsurface, the apparent resistivity can be taken as the true resisitivity. Ground electrical conductivity 'σ' is the reciprocal of the ground resistivity.

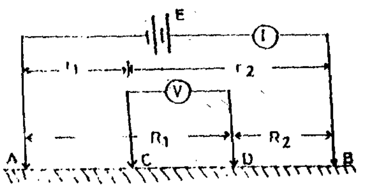

Fig 1 : Wenner arrangement for obtaining apparent resistivity

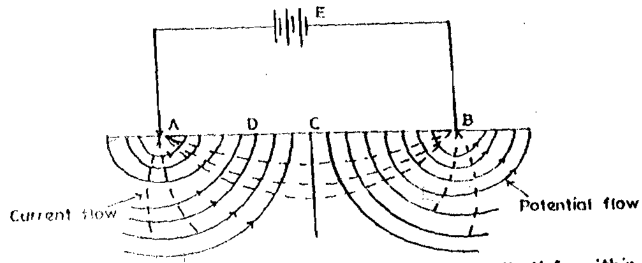

Fig 2: Current and Equipotential surface distribution within homogeneous medium

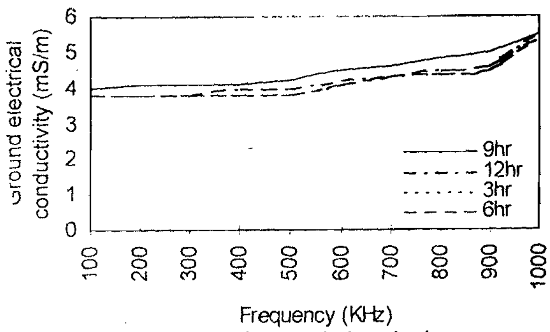

Fig.3 : Variation of ground electrical conductivity with signal frequency during the dry season at different hours of the day

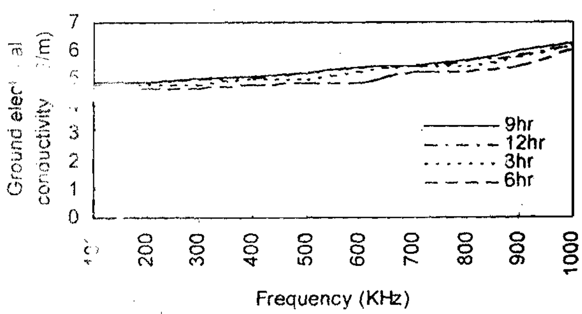

Fig.4 : Variation of ground electrical conductivity with signal frequency during the wet season at different hours of the day

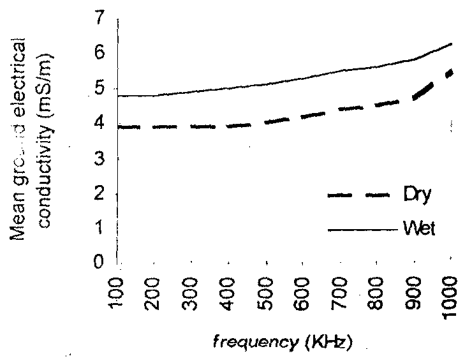

Fig. 5 : Variation of mean ground electrical conductivity with signal frequency for both seasons

Table 1: The mean ground electrical conductivity measured at different hours of the day for different signal frequencies at 40cm depth for dry season.

Frequency	Ground Electrical Conductivity in mS/m at different hours of the day			
(Hz)	9hr	12hr	3hr	6hr
100	4.0	3.8	3.8	3.8
200	4.1	3.8	3.8	3.8
300	4.1	3.8	3.8	3.8
400	4.1	4.0	3.8	3.8
500	4.2	4.0	3.8	3.8
600	4.5	4.2	4.1	4.1
700	4.6	4.3	4.3	4.3
800	4.8	4.5	4.4	4.4
900	5.0	4.6	4.5	4.5
1000	5.5	5.5	5.4	5.4

Table 2: The mean ground electrical conductivity measured at different hours of the day for different signal frequencies at 40cm depth for wet season.

Frequency	Ground Electrical Conductivity in mS/m at different hours of the day			
(Hz)	9hr	12hr	3hr	6hr
100	4.9	4.8	4.7	4.6
200	4.9	4.9	4.8	4.7
300	5.0	5.0	4.8	4.7
400	5.1	5.1	5.0	4.8
500	5.2	5.2	5.0	4.9
600	5.4	5.4	5.3	4.9
700	5.5	5.5	5.5	5.3
800	5.7	5.7	5.5	5.3
900	6.0	5.9	5.8	5.5
1000	6.3	6.2	6.2	6.1

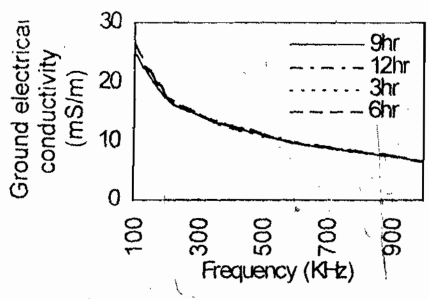

Fig. 6 : Variation of skin depth with signal frequency during the dry season at different hours of the day

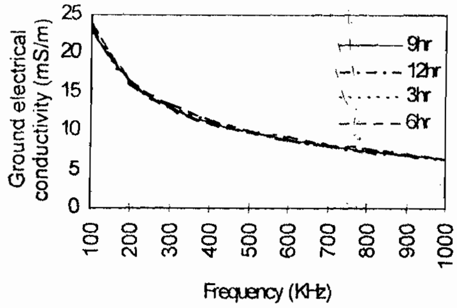

Fig. 7 : Variation of skin depth with signal frequency during the wet season at different hours of the day

Table 3: The skin depth at different hours of the day for different signal frequencies at 40cm depth for dry season.

Frequency (Hz)	Skin Depth at different hours of the day			
	9hr	12hr	3hr	6hr
100	25.16	25.82	25.82	25.82
200	17.58	18.26	18.26	18.26
300	14.35	14.91	14.91	14.91
400	12.43	12.58	12.91	12.91
500	10.98	11.25	11.55	11.55
600	9.69	10.03	10.15	10.15
700	8.87	9.17	9.19	9.19
800	8.12	8.39	8.48	8.48
900	7.5	7.82	7.91	7.91
1000	6.79	6.79	6.85	6.85

Table 4: The skin depth at different hours of the day for different signal frequencies at 40cm depth for wet season.

Frequency (Hz)	Skin Depth at different hours of the day			
	9hr	12hr	3hr	6hr
100	22.74	22.97	23.22	23.47
200	16.08	16.08	16.24	16.42
300	12.99	12.99	13.26	13.4
400	11.14	11.14	11.25	11.49
500	9.87	9.87	10.07	10.17
600	8.84	8.84	8.92	9.28
700	8.11	8.11	8.11	8.26
800	7.45	7.45	7.59	7.73
900	6.85	6.91	6.97	7.15
1000	6.34	6.39	6.39	6.44

The depth at which the signal would have been attenuated to about 37% of its initial value at the surface called the skin depth was also computed using the relation

$$= \frac{1}{\sqrt{\pi f \mu \sigma}} \qquad (10)$$

where f is the signal frequency (Hz), μ is the permeability of free space ($\mu = 4\pi \times 10^{-7}$ H/m) and σ is the conductivity measured in Ohm^{-1} m^{-1}.

RESULTS AND DISCUSSION

In this study, ground electrical conductivity was measured at 40cm depth. Tables 1 and 2 show the mean ground electrical conductivity obtained at 9hrs, 12hrs, 3hrs and 6hrs of the day for frequencies ranging from 100 kHz - 1MHz at 40cm depth for the dry and the wet seasons respectively. Tables 3 and 4 show the means skin depth calculated for the 9hrs, 12hrs, 3hrs and 6hrs for the two seasons respectively. Figures 3 and 4 reveals a constant ground electrical conductivity up to the frequency of about 500 kHz and a steady exponential rise at higher frequencies for the two seasons considered. Figure 5 shows the mean electrical conductivity for both the dry and the wet seasons. The figure shows that the mean conductivity during the wet season is higher than that of dry season. The values range from 3.5mS/m - 5.0mS/m for the dry season and 4.6mS/m - 6.3mS/m for the wet season. This observation could be attributed to the complex nature of the medium considered. The figures show that the daily hourly measurement of ground electrical conductivity is of little significance with a maximum difference of about 0.50 ± 0.13 mS/m between the 9hrs and 6hrs for the two seasons considered. Figs 6 and 7 show the variation of the skin depth with frequency at different hours for the two seasons respectively. It is observed that the depth of penetration decreases exponentially with frequency in both cases with values ranging from 6.79m to 25.82m for the dry season and 6.34m to 23.47m for the wet season. The ground electrical conductivity obtained in this work for both the dry and the wet seasons were within the range 1-10mS/m predicted by Ajayi and Owolabi (1975), which were derived from propagation curves of measured electric field strength.

CORRELATION COEFFICIENT ANALYSIS

The correlation between the signal frequency and the measured ground electrical conductivity at different hours of the day for both seasons was obtained using the statistical analysis toolpack of Microsoft Excel 5.0. A good rule of dumb with $r \leq 0.2$ for slight correlation, $0.2 < r \leq 0.4$ for low correlation, $0.4 < r \leq 0.7$ for moderate correlation, $0.7 < r \leq 0.9$ for high correlation and $0.9 < r \leq 1.0$ for very high correlation was used. The result revealed a very high correlation for 9.00 hour of the day (0.9381) and a high correlation for 12.00 hour (0.8905), 3.00 hour (0.8598) and 6.00 hour (0.8591) of the day during the dry season and very high correlation for 9.00 hour (0.9665), 12.00 hour (0.9834), 3.00 hour (0.9655) and 6.00 hour (0.9242) of the day during the wet season .

CONCLUSION

Signal energy propagation in horizontal direction over the earth's surface is affected by ground parameters such as its electrical properties . Energy is obtained from the guided wave along the earth's surface during propagation leading to the attenuation of the signal. The ground electrical conductivity has been measured as a function of the radio frequency signal in the medium broadcast band. Constant ground conductivity was noticed between 100kHz and 500kHz with a slight exponential rise between 600kHz and 1000kHz. The conductivity measurements made at some specified hours of the day did not reveal any significant variation of ground conductivity. The study also show that ground conductivity is slightly higher during wet season than the dry season. The depth of penetration (skin depth) decreases exponentially with frequency for the two seasons considered. It is important to note that the variation in the tropical ground parameters should be incorporated in the design and construction of transmitters and antenna systems for maximum performance in the tropical environment. The very good correlation obtained in this study shows the reliability of this method in the determination of ground electrical properties for medium wave broadcast planning.

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