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MEASUREMENT OF GROUND ELECTRICAL CONDUCTIVITY FOR PLANNING MEDIUM WAVE RADIO BROADCAST STATIONS IN SOUTH WESTERN NIGERIA.

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Abstract. Results of propagation measurements are often required to improve the coverage of Medium Frequency (MF) broadcast transmitters. To achieve this, ground electrical conductivity measurement is one of the parameters often determined. In this study, ground conductivity has been measured around MF radio transmitters in some parts of Western Nigeria, using the Vertical Electrical Sounding (VES) technique based on the Wenner Array geophysical prospecting method. Four of the radio transmitters belong to the Ondo State Radio Corporation (ODRC) and are located at Irese and Oba-Ile (both near Akure), Okitipupa, and Ido-Ani, while one each belongs to the Ekiti State Broadcasting Service (ESBS) at Ifaki-Ekiti, and the Osun State Broadcasting Corporation at Osu. The mean ground electrical conductivity obtained in this study ranged from 1.99 ± 0.30 mS/m at Okitipupa to 5.41 ± 0.81 mS/m at Ido-Ani. Investigation shows that the penetration depth at the frequency of transmission of each station varies from a minimum of 6.70 ± 0.43 m at Ido-Ani at a transmitting frequency of 1035 kHz to a maximum of 13.0 ± 0.7 m at Okitipupa at a transmitting frequency of 765 kHz.

1. INTRODUCTION

The MF broadcast band is one of the most extensively used of the radio spectrum, but whose propagation problems are often less studied. The energy radiated from a transmitting antenna may reach the receiving antenna over any of many possible propagation paths. These may be due to reflection and scattering in the ionosphere (sky waves), due to reflection and scattering in the troposphere (tropospheric waves) or may be in the form of energy propagated in horizontal directions over other paths near the earth's surface, but which will be affected by the parameters of the ground and the troposphere (ground waves). The ground wave is further classified into space waves and surface waves. The space wave can be either the direct wave or the ground reflected wave. Space wave on the other hand is guided along the earth's surface, and the ground during propagation abstracts energy from it. The attenuation of the space wave is therefore directly affected by the electrical constants of the earth along which the wave travels.

An antenna is usually a length of wire or a hollow conducting tube, which can be excited by current flow through it, thereby producing electric and magnetic fields that are radiated into space as electric and magnetic flux. Thus, when an antenna is connected to, or situated very close to the ground, the ground becomes part of the radiating system. The vertical conductor produces a vertical electric field that extends throughout the ground, thus making the ground to act as a conducting surface or mirror for the radiation. A vertical antenna and its mirror image in the ground correspond to a dipole, whose lower half lobe radiation pattern is cancelled by the reflected waves from the ground, which combine with the direct wave. The resulting loss of radiation is responsible for the relative increase in the signal strength just above the ground in the horizontal and vertical directions when the conductivity of the ground is sufficiently good [1].

At the MF broadcast band (525-1605 kHz), transmitting and receiving antenna systems are vertical radiators situated on or close to the ground, and with typical height of the order of a quarter wavelength. The earth, although not a good conductor compared with metals is by no means a perfect dielectric, but has finite conductivity, which is usually taken into account in installing antenna systems as well as in planning for medium wave broadcast. Grounded antenna will therefore be affected by the electrical properties of the earth, which include the relative dielectric constant ε_r, the relative permeability μ_r, and the conductivity σ. Since the earth is reasonably non-magnetic, free space permeability μ_0 is usually assumed. However, for propagation over a smooth and homogeneous earth, ground conductivity rather than the dielectric constant, is the dominant electrical parameter at medium frequencies. Ground conductivity depends on several factors such as the ground moisture content, vegetation growth, the geological structure and so on. [2]. These factors may vary with time, hence the temporal variations of the field strength of the MF transmitter. The knowledge of the ground conductivity for a proposed MF or HF station is useful in determining the requirements for a good ground screen system, so as to minimize antenna efficiency [3]. For instance, lightning discharge requires the path of least resistance for the flow of high voltage electrons (a path which is offered by the material of the mast) to the ground below which is at a very low negative potential. When the ground on which an antenna mast is situated does not have a good conductivity, there may be heat built-up on the mast during severe thunderstorm, which may damage the antenna and its mast. In addition, high resistance of the ground may short circuit the radio frequency signal leading to a collapse of the signals. In such situations, information about the conductivity of the ground can help to improve signal radiation from the antenna.

The objective of this study is to make measurement of ground conductivity in the vicinity of MF radio transmitters. Todate, there is still a dearth of information on the direct measurement of ground conductivity for radio propagation studies in Nigeria. Field strength signal measurement at Medium Frequencies has been reported in some parts of Nigeria by [4], and by the Electrical Communications Consultancy Unit (ECCU) of the Obafemi Awolowo University, Ile-Ife [5]. In these reports, the observed values of the ground conductivity which were derived from propagation curves of measured electric field strength data are in the range1-10 mS/m [3] and also shows that the conductivity of the earth may range between 0.1-30 mS/m. Surprisingly, a good number of the stations visited in the course of this investigation did not have available information on ground conductivity around the transmitting mast.

The study covers radio stations in three states in South-west Nigeria (Osun, Ekiti, Ondo). In all, six stations were covered as shown in Fig.1. These are at Osun Radio at Osu on frequency 891 kHz, Ekiti State Broadcasting Service, Ifaki-Ekiti on frequency 549 kHz, Ondo Radio Corporation at Irese on frequency 531 kHz, Oba-Ile on 711 kHz, Okitipupa on 765 kHz, and Ido-Ani on 1035 kHz. Only three of the stations (Irese, Oba-Ile and Ifaki) were on air during the measurement campaign. At each of the stations the depth at which the radiowave would have been attenuated to about 37% of its value at the surface called the skin depth was also investigated.

2. FIELD MEASUREMENT OF EFFECTIVE ELECTRICAL CHARACTERISTICS

2.1 Relevant Maxwell Equations

Since both electric and magnetic fields are radiated into space as electromagnetic waves, Maxwell's equations relate the electromotive force to the time derivative of the magnetic displacement, and the magnetomotive force to the total current around a loop by the following relations [6].

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

$$\nabla \times E = \left(\sigma + \varepsilon \frac{\partial}{\partial t} \right) E \quad (2)$$

where ε and σ are the dielectric constant (permittivity), and the conductivity of the medium. If the variation of electric field E with time is sinusoidal then,

$$E = E_0 \exp(j\omega t) \quad (3)$$

where ω is a measure of the frequency of the wave, then

$$\frac{\partial E}{\partial t} = j\omega E \quad (4)$$

Thus, equation (2) becomes

$$\nabla \times H = \frac{\partial}{\partial t} \left(\varepsilon - j \frac{\sigma}{\omega} \right) E \quad (5)$$

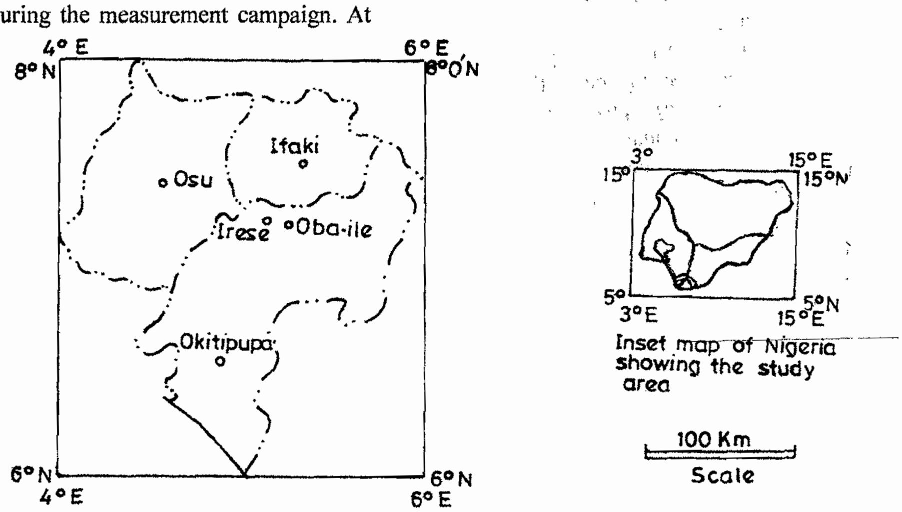

Fig.1: Map of Ondo, Osun and Ekiti showing study locations

2.2 Survey of Some Existing Measurement Techniques

Most of the methods used for measuring effective electrical characteristics of the earth measure the field strength, the ground conductivity values are then derived from the resulting curves. Among such methods are the wave-tilt, the attenuation technique, measurement of antenna input impedance, the geophysical prospecting methods, and so on. Ajayi and Owolabi [4] used the attenuation method to measure field strength around the OYO transmitter in Ibadan, and later derived the conductivity values from the field strength data. Kuhn and Taumer [7] also used the wave-tilt method to measure field strength distribution from which ground conductivity was derived for the defunct German Democratic Republic. The probe method of the geophysical technique is particularly useful in planning antenna installation [8]. It is this method that has been adopted in this study with the probe separation sufficiently adjusted so that measurements will result in effective conductivity. A particularly very simple, versatile and easy-to-use probe method is the Wenner Array Method.

2.3 The Wenner Array Method of Measuring Ground Conductivity

Wenner array method is an electrical prospecting method in which current is introduced into the ground through a pair of outer electrodes, while the impressed voltage, which is distributed in the space between these electrodes, is measured between two other inner probes. For a piece of conductor of length L and cross sectional area A, the relationship between the resistivity ρ, resistance R, the measured current I, and the potential difference V is given by

$$\rho = R\left(\frac{A}{L}\right) = \frac{\Delta V}{I}\frac{A}{L} \quad (6)$$

For infinitesimal change in the conductor size,

$$\rho = \frac{\Delta V/L}{I/\Delta A} \quad (7)$$

A typical practical geometry employing the Wenner Array Method is shown in Fig.2. The potential difference between electrodes B and C for a semi-infinite earth of uniform resistivity ρ, is expressed [9] by

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

where K is the geometric factor defined as

$$K = \left[\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{R_1} - \frac{1}{R_2}\right)\right] \quad (9)$$

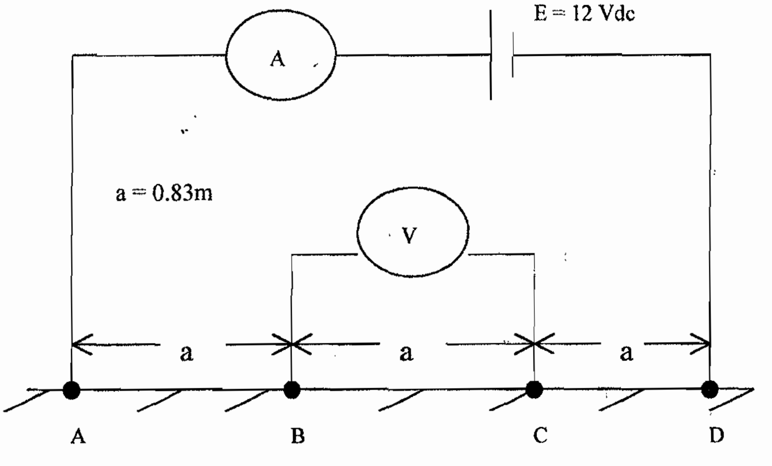

Figure 2: Typical geometry of the Wenner Array method

where r_1 is the distance from the potential electrode B to the current electrode A

r_2 is the distance from the potential electrode B to the current electrode D.

R_1 is the distance from the potential electrode C to the current electrode A.

R_2 is the distance from the potential electrode C to the current electrode D. Also,

$r_1 = R_2 = a$ and $r_2 = R_1 = 2a$.

The apparent resistivity, which is independent of electrode positions, can then be computed from

$$\rho_a = \frac{2\pi\Delta V}{I}K^{-1} \quad (10)$$

If it is assumed that the apparent resistivity is uniform within the subsurface, this value will then be equal to the true resistivity of the subsurface structure. Therefore, the resistivity can be calculated from the relation

$$\sigma = \rho^{-1} \quad (11)$$

The skin depth at each of the stations was computed using the relation

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \quad (12)$$

where f is the frequency (kHz), μ is the permeability taken to be that of free space

$\mu_0 (= 4\pi \times 10^{-7}$ H/m) and σ is the average conductivity at the site

2.4 Experimental Set up

Ground conductivity was determined using the technique of continuous profiling in which a constant electrode spacing of 0.83 m is maintained along traverses measured with the radio transmitter mast at the center. Current was introduced into the ground by the method of Vertical Electrical Sounding (VES). The array is moved laterally along the traverses for the constant separation. VES ropes were used to indicate electrode positions for vertical sounding along a 25 m traverse for four radials around the transmitter mast. Each of the 25 m traverses was divided into 10 VES stations of 2.5 m long each. The constant probe separation 'a' (Fig.2) of 0.83 m was used, because, in the Wenner array method, 'a' distance separates one potential electrode from the adjacent current electrode, and this distance is one-third of the distance between the two outer current electrodes. The distance between the outer current electrodes has been taken as 2.5 m in this study. From equation (9) and Fig.1, $r_1 = R_2 = 0.83$ m and $r_2 = R_1 = 1.66$ m.

During the field campaign, four aluminium probes each 50 cm long were used as electrodes. One 12 Vdc source, two digital multimeters, signal generator (to investigate frequency characteristics), flexible wires, pegs, and so on were employed to investigate the resistivity of the earth. Average ground temperature was 28^0C during the first phase of the measurement campaign in November 1997 at three of the stations (Irese, Ifaki, and Osu), while it was about 24^0C during the month of August at Oba-Ile, Okitipupa, and Ido-Ani. At some of the stations where electric power was available, the frequency characteristic of ground conductivity with depth was investigated. The electric current flowing between the two outer electrodes, and the potential difference between the two inner electrodes were measured at each of the 10 VES points. The ground resistivity and ultimately the conductivity, were then deduced using equations (10) and (11).

3. RESULTS

The location of the transmitters in South-west Nigeria is as shown in Fig.1 and the average results of the measurement for each VES point in the six stations are summarized in Table 1. It can be seen that the conductivity at Ido-Ani (location) is highest, and in contrast, that at Okitipupa, about 46 km from the Atlantic Ocean is lowest. The low value at Okitipupa may have been due to the significant drain and the slope of the area. Enquiry at Ifaki-Ekiti and Ido-Ani shows that there is a layer of buried artificial screen under each mast. Despite this, the average conductivity for Ifaki area is particularly low within the range for very dry ground (~2 mS/m) while that of Ido-Ani is only in the range for average ground (~2-10 mS/m) [10]. In areas where there are no ground screens, there is need to install artificial ground screen to improve pick up signals, and where they exist, there may be the need to improve on what is available. The measured conductivity at the stations is generally within the range for very dry and average ground (2-10 mS/m).

Table 2 shows typical variation of conductivity with frequency for depths of 20 and 50 cm at Oba-Ile and Ifaki-Ekiti. At the Irese station of the Ondo State Radio Corporation, vertical sounding was only carried out to a depth of 25 cm due to the presence of massive rock formation below this depth, and in the vicinity of the mast.

This investigation was done only at Irese, Oba-Ile and Ifaki because there was no power supply to the other stations. In fact, these other stations have been off air for quite a long time. The conductivity values obtained increase with depth.

Fig.3 shows the variation of skin depth with frequency at the transmitter sites. It is observed that the depth of penetration decreases exponentially with frequency. On the average, there is fairly good comparison between the results obtained at Okitipupa, Ifaki, and Osu, also the results for Irese and Oba-Ile (about 10 km apart) agree quite well. The values for Ido-Ani are lowest at all frequencies. On station to station basis, Okitipupa with a frequency of 765 kHz will have a penetration depth of 13 m at this frequency, while Ifaki at a frequency of 549 kHz will have a penetration depth of 15 m. Osu at a frequency of 891 kHz will have a penetration depth of 10.7 m, while Oba-Ile (711 kHz), Irese (531 kHz) and Ido-Ani (1035 kHz) will have penetration depths of 10.8 m, 11.3 m, and 6.7 m respectively. The results taken together ranged from a highest value of about 16 m at 500 kHz at Okitipupa to a minimum value of 6.25 m at Ido-Ani at 1200 kHz.

4. CONCLUSION

In this study, ground electrical conductivity has been measured around six MF radio transmitters in some parts of South-west Nigeria. Results obtained varied from 1.99 ± 0.30 mS/m to 5.41 ± 0.81 mS/m. The variation of conductivity with depth was also investigated, and results show that the variation is poorest at Ifaki-Ekiti. The ground drain at Ifaki-Ekiti coupled with its average height of 581m above sea level might have been responsible for the dryness and very poor conductivity variation with depth. Results were also obtained for the penetration depth of the MF at the stations.

Table 1: Conductivity values σ (mS/m) along each VES line for six the transmitters.

VES POINTS	Ground Temperature 28^0 C			Ground Temperature 24^0 C		
	IFAKI σ (mS/m)	IRESE σ (mS/m)	OSU σ (mS/m)	OBA-ILE σ (mS/m)	OKITIPUPA σ (mS/m)	IDO-ANI σ (mS/m)
1	6.71	2.45	0.65	2.63	4.45	10.79
2	1.12	4.51	0.66	2.65	2.93	9.78
3	1.72	2.50	3.42	2.97	2.09	6.11
4	1.56	2.50	4.00	3.00	1.50	4.47
5	5.85	11.06	1.77	3.17	1.67	4.96
6	1.79	1.66	3.24	3.04	1.41	4.27
7	2.44	2.50	4.26	3.23	1.47	4.42
8	1.70	3.04	3.70	3.38	1.41	3.40
9	1.60	0.92	3.93	3.38	1.42	3.30
10	1.63	6.02	3.02	3.42	1.55	2.64
Average Value	2.61 ± 0.56	3.72 ± 0.01	2.87 ± 0.36	3.09 ± 0.08	1.99 ± 0.30	5.41 ± 0.81

Table 2: Variation of conductivity with frequency at some depths at some of the stations.

Probe Depth (cm)	Ground Conductivity σ (mS/m)			
	20.0		50.0	
Freq. (kHz)	Oba-Ile	Ifaki	Oba-Ile	Ifaki
500	2.47	0.009	3.31	0.25
600	2.45	0.011	3.32	0.17
700	2.45	0.013	3.32	0.14
800	2.44	0.014	3.32	0.13
900	2.43	0.015	3.34	0.13
1000	2.43	0.017	3.32	0.11
1100	2.43	0.018	3.33	0.11
1200	2.43	0.018	3.32	0.11

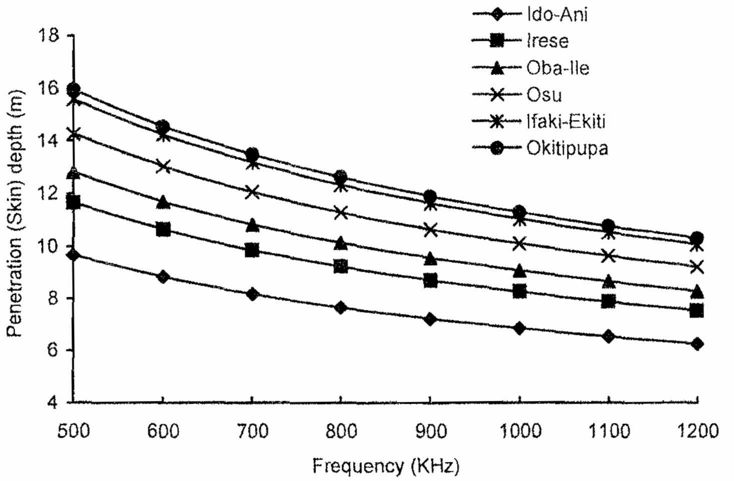

Fig.3: Frequency characteristics of penetration depth at the stations

The study covers very limited area, and different seasons as shown in Table 1, it will be appropriate therefore to repeat the measurement at more sites and to cover both wet and dry seasons for each station. Thus, it may not be too adequate for now to adopt the results as completely representative of the conductivity map over the entire region (SW, Nigeria) in which they were taken. In the meantime, measurement has been done for the two seasons at Oba-Ile where the results show an average conductivity of 3.80 ± 0.05 mS/m for the dry season, and 3.09 ± 0.08 mS/m for the wet season.

The use of artificial ground screen is recommended for all the stations, and where there are existing mats, it is suggested that such should be reinforced as the effect of the present one yields less than average value. A good ground screen will, in addition to improving ground constants, thereby increasing signal pick up, also enhance system performance that will be less dependent on weather conditions. Use can be made of screens with lengths of about five times the antenna wavelength, as they have the effect of stabilising antenna impedance needed for improving circuit matching.

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