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THE ABDUS SALAM INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

TROPOSPHERIC VHF RADIOWAVE PROPAGATION MEASUREMENTS IN A TROPICAL LOCATION IN NIGERIA

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Abstract

A major task for the radiocommunication engineer in designing a communication system is to be able to predict the behaviour of the radio signal from the point of transmission to the receiving point. Usually, the radiocommunication engineer would have available propagation data that will enable him to demonstrate that the radiocommunications system will meet both the performance and the availability objectives. The data obtained from a 10-month period of terrestrial over-the-horizon propagation measurements, carried out in southwestern part of Nigeria, have been statistically analyzed in this study. The findings from the analysis show that the measured values of field strength were significantly high during the dry months of November to March, the night time and early morning hours while lower values were obtained during the wet months of April to October. In particular, it is observed that the dry month of March recorded the highest median value of field strength while the wet month of July recorded the lowest. These high values of field strength observed during the dry months are attributed to anomalous propagation effects such as extreme super-refractivity and ducting which are often prevalent in the West African tropical sub-region.

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1. Introduction

In planning radiocommunication systems, it is realistic to have design targets for the maximum percentages of time for which the circuit may be interrupted. Allowances have to be made for equipment breakdowns, propagation and interference problems. Preliminary calculations before the system design is embarked upon therefore involve the signal strength expected at the receiving point, its behaviour with time, and the probability of interference between a given system and another system operating on the same or adjacent frequency channel. The parameters involved fall into two categories. The first category consists of parameters within the control of the design engineer, such as the transmitter power, frequency, type of signal modulation, type of aerial structure, and the sites of the transmitter and receiver. The second category consists of parameters that are usually not within his control, such as the nature of the terrain over which the propagation is to be made, and the nature of the propagation medium. A reliable communication system can only be obtained after all relevant parameters are known, and this, therefore, calls for a proper preliminary survey of the path during the design state.

The propagation of radio frequency energy at the surface of the Earth often poses scientific and regulatory issues for users of the spectrum, as it introduces a need for regulation to protect different services with some degree of geographical proximity. Propagation conditions often vary considerably from month to month, and the monthly variability can change significantly from year to year. These statistics of signal variability, are required for spectrum planning and for predicting the performance of systems. In this context it is important to know, for example, the signal level exceeded for large percentages of time or location, for example in the determination of quality of the wanted service or of the service area; and the signal level which occurs for small percentages of time, for example, to determine the significance of potential interference or the feasibility of frequency reuse.

Signals from a “wanted” transmitter would typically travel over paths of 50 km or less in order to ensure, as much as possible, that a satisfactory service is achieved while signals from a potentially interfering station would travel from far greater distances. Hence for most of the time, signals from potentially interfering stations would not affect reception because of the large distances involved. However, there are occasions when radiometeorological conditions occur whereby signals can travel to far greater distances than normal and can arrive in another service area with sufficient strength to cause interference to a wanted service. The purpose of conducting propagation measurements on long-distance propagation paths is, therefore, to acquire knowledge of the likelihood of such interfering signals [1].

As a result of the lack of knowledge, the art and science of planning a tropospheric communication link is extremely complicated. In the planning of any communication link, field surveys are necessary in order to sample and establish the true practical propagation characteristics obtainable over a particular path at a given instance. For low- or medium frequency transmission where ionospheric paths are considered, surveys need only be of short duration in a large number of instances, since they are supplemented by a vast amount of statistical information, which is already available. For VHF transmission propagated over tropospheric paths, relatively long-duration field surveys are necessary because of the inadequate knowledge of the essential properties of the propagation medium combined with the lack of relevant statistical information. To help engineers in the planning of broadcast services (i.e. in the VHF and UHF frequency bands), the International Telecommunication Union (ITU) has developed propagation prediction methods that usually give a representation of field strength values exceeded at 50% of the locations for different percentages of time and path lengths [2]. The set of data upon which these propagation prediction methods are based usually comes from cumulative frequency distributions of field strength measurements considered on a yearly basis. However most of these measurements have been made in temperate regions of the world. As a consequence, they are not very representative of areas subject to anomalous propagation effects such as extreme super-refractivity and ducting which are often prevalent in the West African tropical sub-region [3]. An extensive measurement campaign from tropical regions in Africa is thus necessary to extend knowledge of the propagation characteristics in such regions. This paper presents the results of terrestrial over-the-horizon propagation measurements carried out in a tropical region in Africa [4, 5].

2. Experimental set-up

The transmitting and receiving stations were both in the southwestern part of Nigeria. The propagation link is essentially a land path. Table I gives details of the parameters of the experiment while Fig. 1 shows a section of the map of Nigeria indicating the positions of the transmitter and receiver. The transmitting site at Lagos, lies within latitude $6^0 27^1$N and longitude $3^0 24^1$E while the receiving site at Ile-Ife, lies between latitudes 7^0N and $7^0 35^1$N, longitudes $4^0 20^1$E and $4^0 45^1$E. The climatic condition in Nigeria is tropical, i.e. hot and humid with two main seasons; rainy season (approximately April to October) and dry season (approximately November to March) dominated by hot, dry Harmattan winds. The measurements were initiated in September 1998 and were meant to have a minimum duration of two years. The data received between September 1998 and August 1999 has been statistically analyzed in this paper. A break-down of the receiver occurred in December 1998 and hence no data were recorded during this month.

TABLE I
PARAMETERS OF THE MEASUREMENT

Frequency	100.50 MHz
Tx. antenna height	274 m
Rx.antenna height	10 m
Tx. E.R.P	30 kW
Path distance	200 km

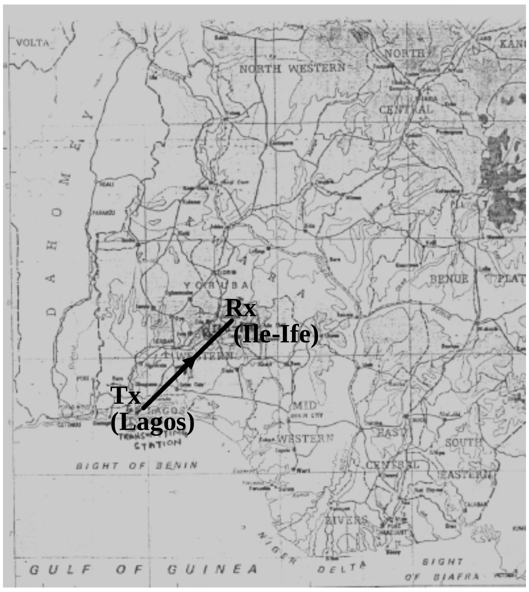

Fig. 1. Locations of transmitting and receiving sites.

The measurement campaign was carried out using a yagi antenna, a field strength meter, a data logger field strength meter and a personal computer. The data logger field strength meter was interfaced to the personal computer. The experimental set-up is shown in Fig. 2.

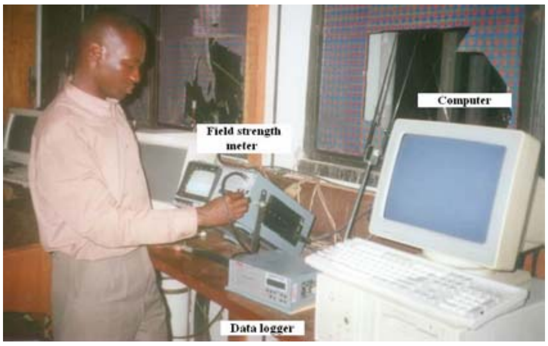

Fig. 2. The measurement system.

The field strength meter measures the received signal level, resulting from a radio transmitter in the VHF band over a path length of 200 km. The personal computer was programmed to sample the received signal level, on a continuous basis, at approximately once every minute. The computer controlled the acquisition of data by using RS232 commands sent to the data logger field strength meter. Data were also downloaded via RS232 and stored on the personal computer.

3. Data processing and analysis

The field strength induced at the terminals of the receiving antenna, i.e. the yagi antenna, was measured with the field strength meter. The received signal levels, as values of voltages, were converted to values of field strength and subsequently statistically analyzed through purpose-written software. The data was processed by ordering the data for diurnal and monthly variations. Great care was taken in ordering the data in terms of identification, i.e. date and time of each measurement and in conversion from signal level, dB (μV), to field strength, dB (μV/m).

The received signal level, V dB (μV), is related to the field strength, E dB (μV/m), at the antenna by [1]

$$E = V + L - G + 20\log f - 32\,. \tag{1}$$

For a characteristic impedance of $50\ \Omega$, where

E is the field strength, dB (μV/m), at the antenna.
V is the received signal level, dB (μV).
L is the loss in dB of the cable that connects the antenna to the field strength meter.
G is the gain in dB of the receiving antenna relative to a $\lambda/2$ dipole.
f is the frequency in MHz.

The cable loss in the experimental set-up is estimated to be -0.84 dB while the gain of the receiving antenna is 12 dB. The frequency of operation is 100.5 MHz. Substituting the different parameter values into equation (1), the received field strength, E dB (μV/m), is given by

$$E = V - 4.8\ \text{dB}\,. \tag{2}$$

In order for the measured field strength in this experiment to be comparable with other VHF field strength measurements, the field strength is subsequently normalized to an e.r.p of 1 kW, thus

$$E = V - 34.8\ \text{dB}\,. \tag{3}$$

Taking into account the possibility of small variations in the transmitted power from time to time, the receiving antenna characteristics and noise measurements, it is estimated that the overall error in the measured field strength values is no greater than $\pm$ 4 dB.

The field strength distribution for the entire database of measurements, normalized to an e.r.p of 1 kW using equation (3), has been computed to show the field strength values at various time percentages of the measurement period. Field strength distributions, normalized to an e.r.p of 1 kW, were also computed to show the values at various time percentages over an entire day for diurnal variations and over a month for seasonal variations.

4. Measurement results and discussion

4.1. Field strength distribution for the entire database

Fig. 3 shows the field strength distribution for the database of measurements, over a 10-month period between September 1998 and August 1999. The figure shows the value of received field strength at different percentages of the entire database of measurement, normalized to an e.r.p of 1 kW. The measurement time corresponded to an entire day (0h to 23h59), except for periods of power outages and equipment failures. The entire database consists of 135,055 field strength values. The field strength value with the highest number of samples in the entire database is 8 dB (µV/m), observed for 5.6 % of the entire database of measurement.

Usually at distances greater than 100 km, VHF and UHF signals are known to become highly variable with time as a result of variations in the refractivity of the troposphere [1]. At certain periods, the formation of inversion layers and ducts enhances the radio signals well beyond the normal horizon. As seen in Fig. 3, for low percentages of the entire database of measurement the received field strength values are tens of decibels greater than the median value of 19 dB (µV/m). For example at 0.4 % of the entire database of measurement, the measured field strength values were 40 dB (µV/m) and 43 dB (µV/m). These are clear indications of a high incidence of interfering signals associated with small time percentages, in the region.

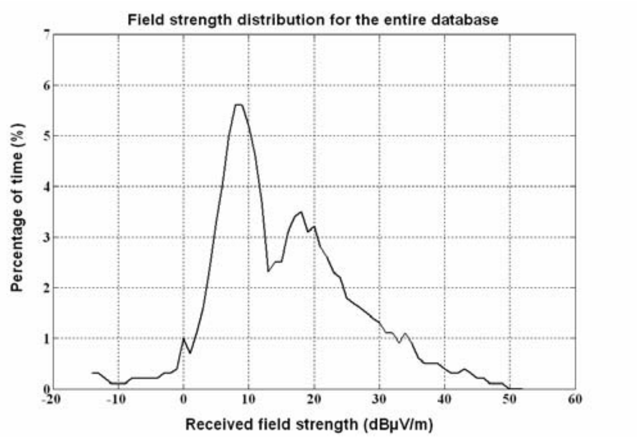

Fig. 3. Field strength distribution for the entire database.

4.2 Monthly field strength distribution

For a more detailed investigation of the measured field strength values, field strength distributions have been derived for each month. These are shown in Figs. 4 & 5. The monthly median field strength values are tabulated in Table II. A comprehensive analysis of these monthly field strength variations are shown in Figs. (6-15). As shown in Table II, the month with the highest median value of field strength is March, i.e. 21 dB (µV/m), while July has the lowest value, i.e. 9 dB (µV/m). This strong seasonal variation of the received field strength is attributed to the prevailing meteorological conditions. The highest value observed in March, which corresponds to the dry season in Nigeria, is attributed to a high incidence of anomalous propagation effects such as extreme super-refractivity and ducting.

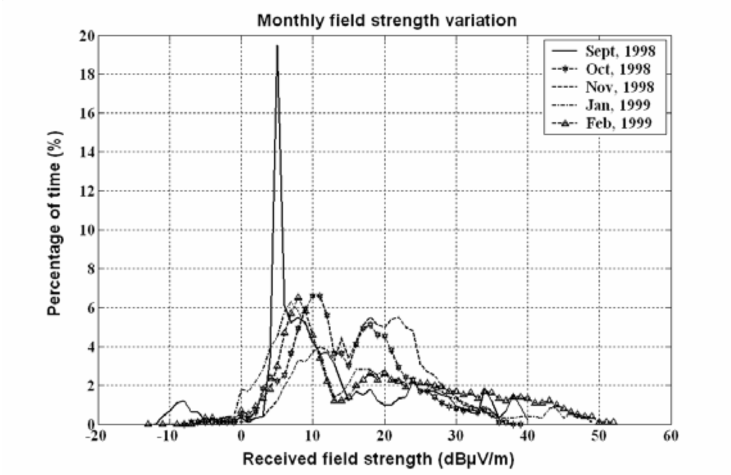

Fig. 4. Monthly field strength variation for Sept – Nov, 1998 and Jan – Feb, 1999.

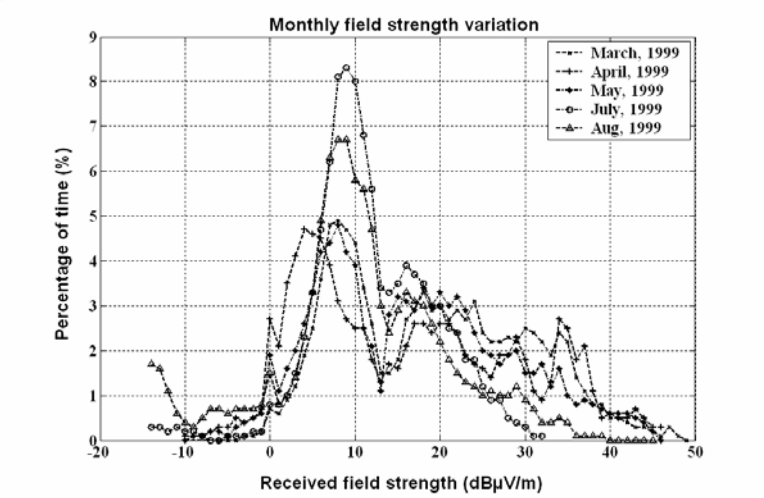

Fig. 5. Monthly field strength variation for March – May, 1999 and July – August, 1999.

TABLE II
MONTHLY MEDIAN FIELD STRENGTH

Month	**Median field strength**
Sept. 1998	14 dB (µV/m)
Oct. 1998	15.5 dB (µV/m)
Nov. 1998	16.5 dB (µV/m)
Jan. 1999	20 dB (µV/m)
Feb. 1999	20.5 dB (µV/m)
March 1999	21 dB (µV/m)
April 1999	18 dB (µV/m)
May 1999	18 dB (µV/m)
July 1999	9 dB (µV/m)
Aug. 1999	15.5 dB (µV/m)

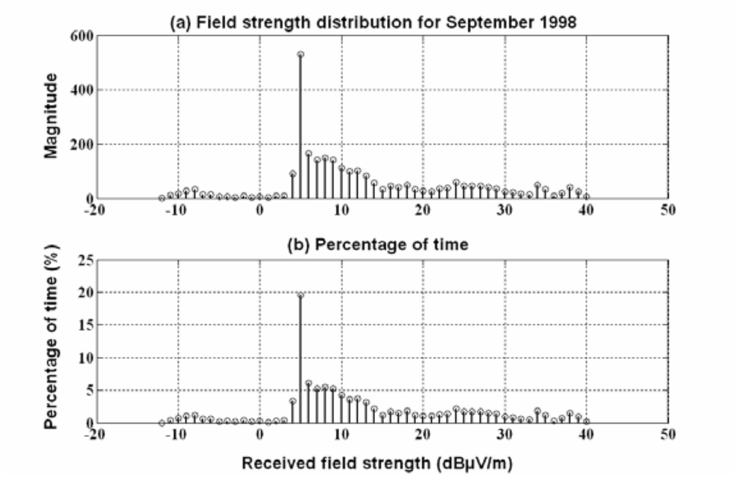

Fig. 6. Field strength variation for September 1998.

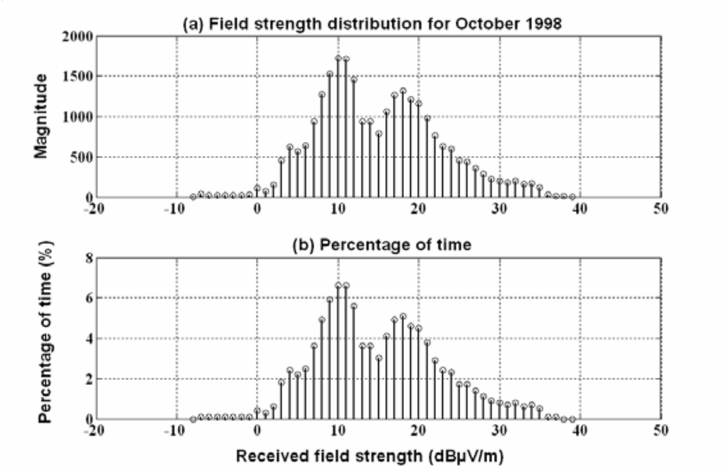

Fig. 7. Field strength variation for October 1998.

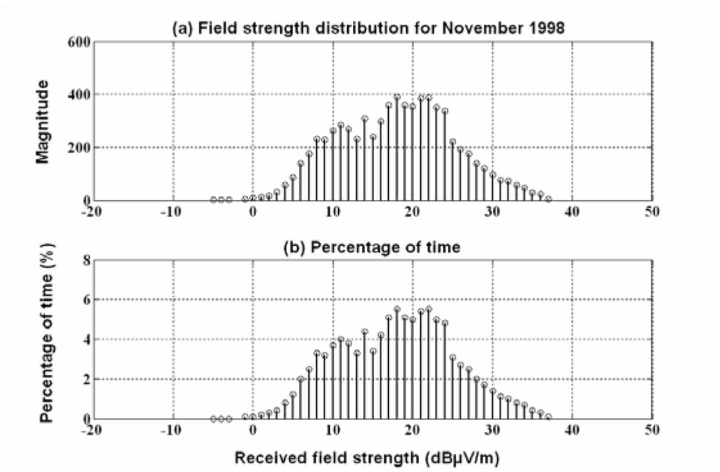

Fig. 8. Field strength variation for November 1998.

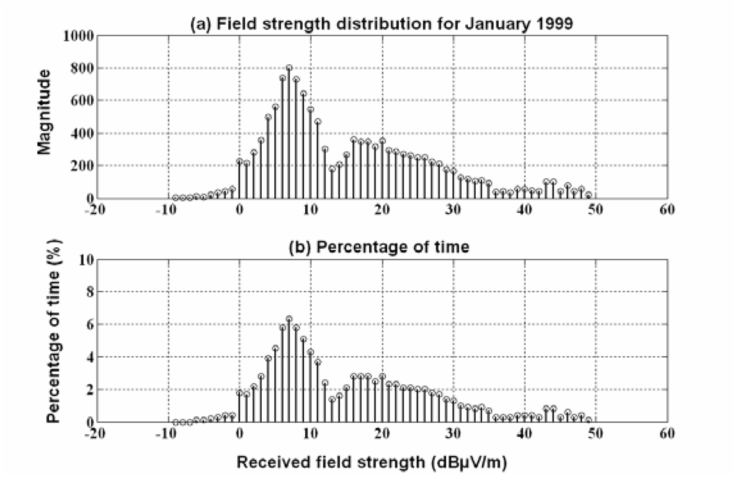

Fig. 9. Field strength variation for January 1999.

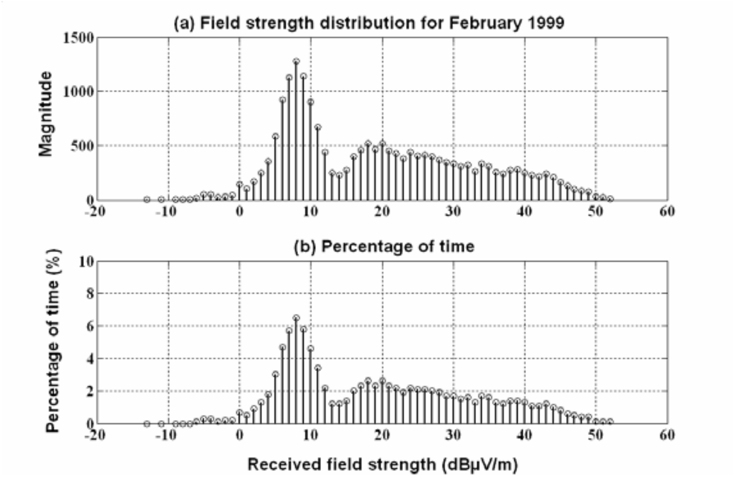

Fig. 10. Field strength variation for February 1999.

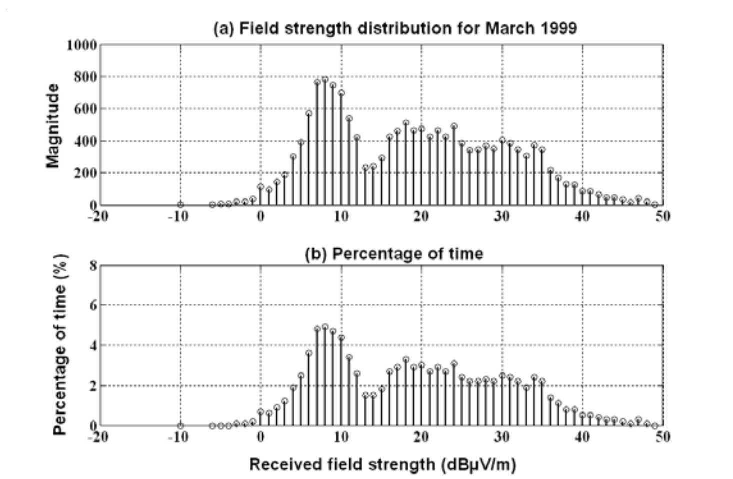

Fig. 11. Field strength variation for March 1999.

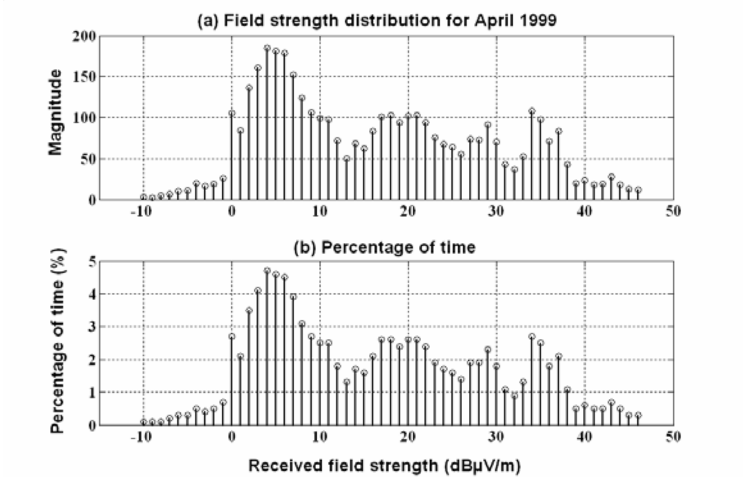

Fig. 12. Field strength variation for April 1999.

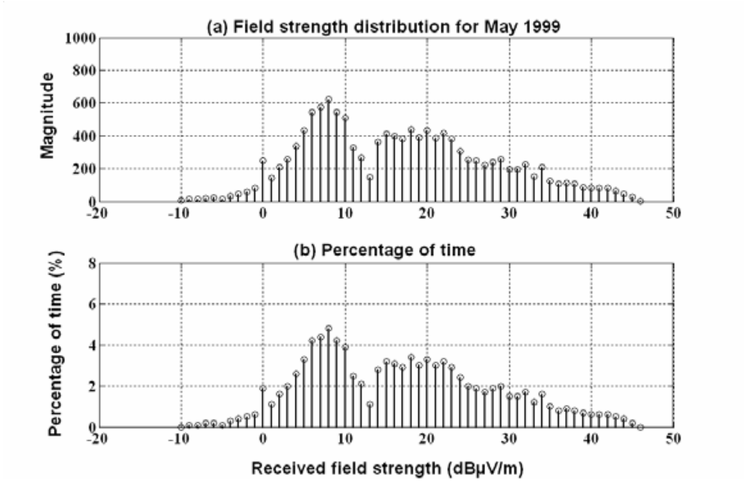

Fig. 13. Field strength variation for May 1999.

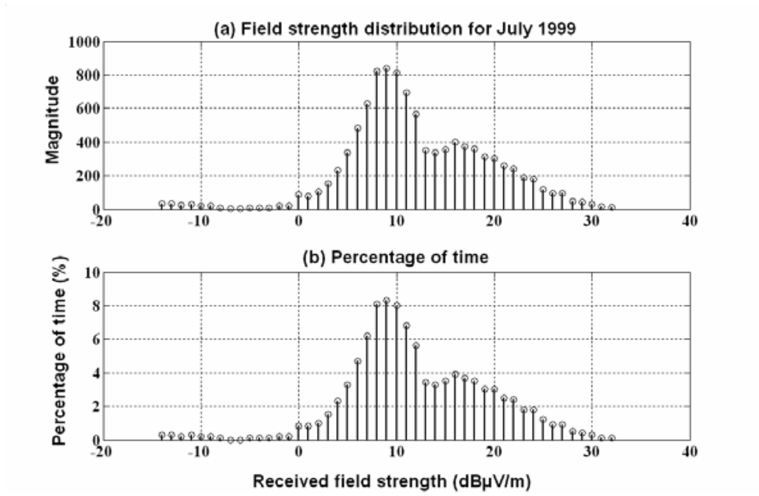

Fig. 14. Field strength variation for July 1999.

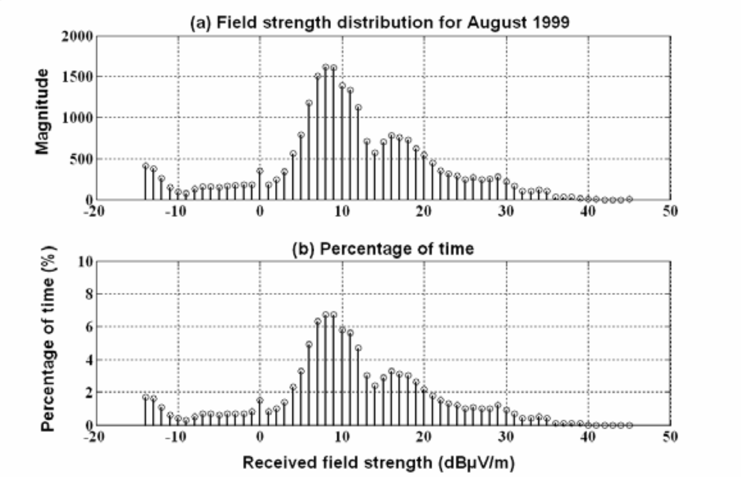

Fig. 15. Field strength variation for August 1999.

For low percentages of time, the received field strength values in the dry months are again tens of decibels greater than the median value. For example a field strength value of 37 dB (µV/m) was received for 0.1 % of the measurement period in November 1998. The median value for this month is 16.5 dB (µV/m). This is shown in Fig. 8 (b).

In the dry month of January 1999, a field strength value of 49 dB (µV/m) was received for 0.1 % of the measurement period while the median value for this month is 20 dB (µV/m). This is shown in Fig. 9 (b). In February 1999, a field strength value of 52 dB (µV/m) was received for 0.1 % of the measurement period while the median value for this month is 20.5 dB (µV/m) as shown in Fig. 10 (b). For March 1999, a field strength value of 48 dB (µV/m) was received for 0.1 % of the measurement period while the median value for this month is 21 dB (µV/m). This is shown in Fig. 11 (b). On the other hand in the wet month of August 1999 for example, a field strength value of 39 dB (µV/m) was received for 0.1 % of the measurement period while the median value for this month is 15.5 dB (µV/m). This is shown in Fig. 15 (b).

The deviation of the monthly field strength from the median values, by several decibels in the dry months, are again attributed to the high incidence of interfering signals associated with small time percentages. This monthly or seasonal variation of the received field strength is in broad agreement with that obtained from similar experiment carried out in Senegal [6].

In addition, it is observed that the field strength distribution during the dry months of January to March 1999 shows almost a regular pattern as seen in Figs. (9-11). This can be attributed to the formation of tropospheric radio ducts along the propagation path for most of the measurement period during these dry months. The formation of the duct along the path causes the signal level to propagate over long distances and cause interference in nearby stations. On the other hand, the field strength distribution during the wet months of September 1998, October 1998, April 1999, May 1999, July 1999 and August 1999 does not show repetitive patterns as seen in Figs. (6, 7, 12, 13, 14 and 15). These strong field strength variations are attributed to situations where the received signal level exhibits frequent deeps and relatively short duration fades, over the wet months, due to attenuation and scattering by rain and obstructions such as buildings or hills.

4.3 Diurnal field strength distribution

To investigate the diurnal variation of received field strength, field strength distributions have been computed over an entire day (i.e. 0h to 23h59) as shown in Figs. (16-20). The daily median field strength values, for typical days in the dry and wet months, are tabulated in Table III. These typical days were selected from months with very high and low median field strength values.

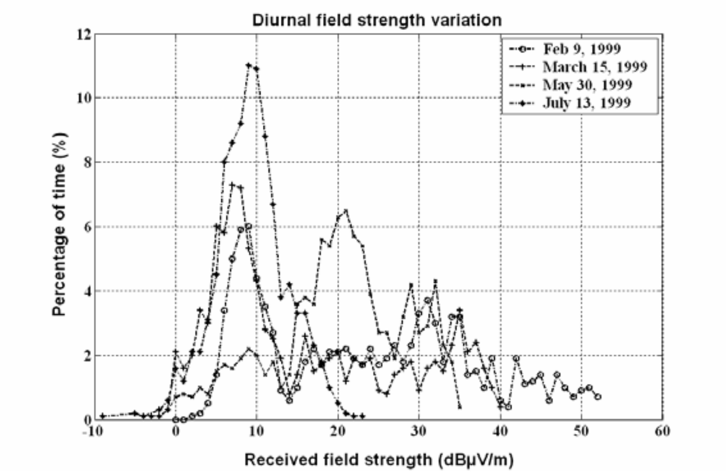

Fig. 16. Diurnal field strength variation.

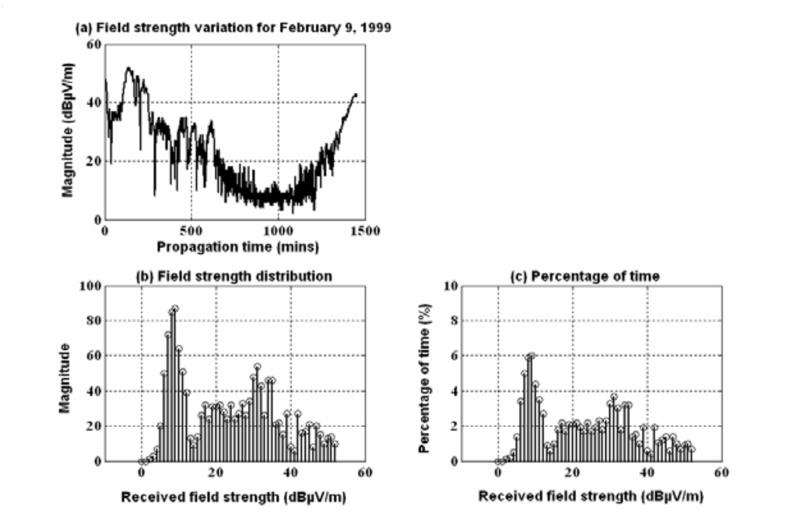

Fig. 17. Field strength variation for February 9, 1999.

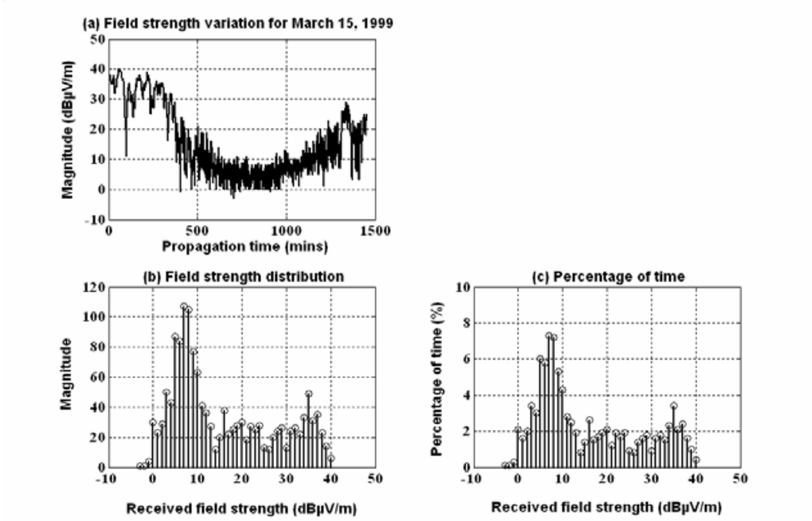

Fig. 18. Field strength variation for March 15, 1999.

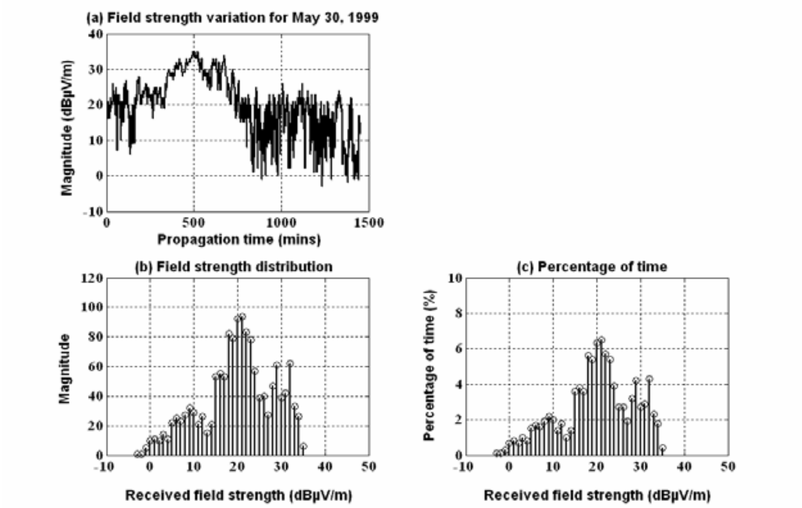

Fig. 19. Field strength variation for May 30, 1999.

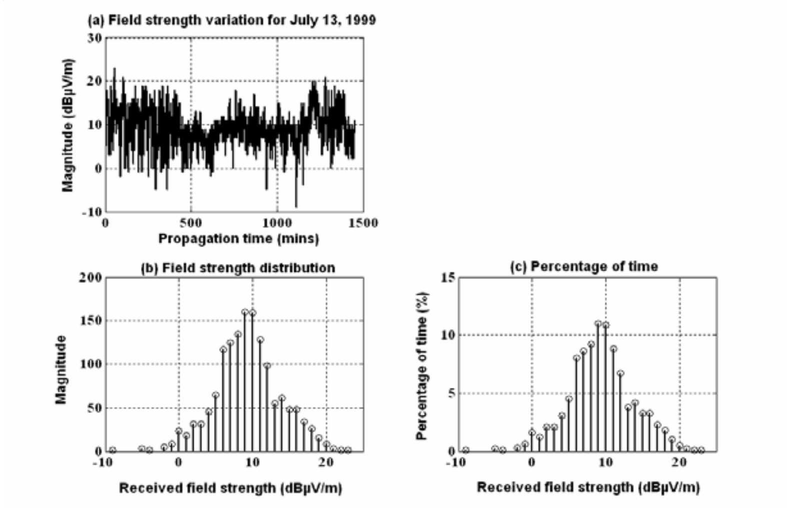

Fig. 20. Field strength variation for July 13, 1999

TABLE III
DAILY MEDIAN FIELD STRENGTH

Day	Median field strength
Feb. 9, 1999	26 dB (μV/m)
March 15, 1999	18.5 dB (μV/m)
May 30, 1999	16 dB (μV/m)
July 13, 1999	9 dB (μV/m)

As observed in Fig. 16, the received signal strength shows a strong diurnal variation. As shown in Table III, the daily median field strength has the highest value in a typical day in the dry month, i.e. February 9, while the lowest value occurs within the wet month, i.e. July 13. Distinct diurnal effects were observed in February 9 and March 15, as shown in Figs. 17 (a) & 18 (a) respectively. The maximum signal strength occurs during the night and early morning hours while the lowest value occurs during the daytime. It is also observed that February 9 has the highest incidence of interfering signals associated with small time percentages, while July 13 has the lowest. For example a field strength value of 52 dB (μV/m) was received for 0.7 % of the measurement period in February 9, 1999. The median value for this day is 26 dB (μV/m). On the other hand, a field strength value of 23 dB (μV/m) was received for 0.1 % of the measurement period in July 13, 1999 with a median value of 9 dB (μV/m). These are shown in Figs. 17 (b & c) and 20 (b & c) respectively.

The meteorological mechanism attributed to these diurnal effects could be explained as follows. During the daytime, the sun heats the earth's surface. After sunset the earth's surface cool quickly as a result of radiation, thus giving rise to an increase in air temperature with height in the lower troposphere. This leads to the formation of an inversion layer and ducting. In the subsequent morning, after sunrise, the inversion layer is destroyed due to solar heating and the signal strength decreases.

As shown in Figs. 17 (a) and 18 (a), generally the entire day in the dry month can be divided into three different periods. A period when the signal is strong with frequent deep and relatively short duration fades, a period of low signal strength and lastly a period of signal enhancement usually with the same properties as the first period. This pattern is however not observed in typical days within the wet month, such as shown in Figs. 19 (a) and 20 (a). On the other hand, low signal strength was observed in the wet months. The low signal strength observed during this period, for example in July 13, may be attributed mainly to the high incidence of rain in the wet months.

These anomalous propagation effects are major source of interference between stations working in the same frequency band in the West African tropical sub-region. These effects can have serious consequences when frequencies are to be reused in other parts of the country. As a result, careful planning is required to minimize the incidence of interfering signals. In television reception for example, fixed, roof-mounted directional antennas can be used to discriminate against these unwanted interferences.

5. Conclusions

The data obtained from a 10-month period of terrestrial over-the-horizon propagation measurements, carried out in southwestern part of Nigeria, have been analyzed in this paper. The results obtained from the experiment indicate that high values of signal strength were obtained during the dry months of November to March, with the highest median field strength occurring in March. These high field strength values observed during the dry months, could have serious consequences for planning of VHF radio broadcasting services in the southwestern part of Nigeria since the incidence of interfering signals associated with small time percentages, typically 10 % to 0.1 %, will be high.

Acknowledgments

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