TITLE / APPROVAL PAGE

GROUND-WAVE RECEPTION AND GROUND CONDUCTIVITY

By

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DECLARATION

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All quotations are distinguished by quotation marks and the sources of information are specifically acknowledged by means of references.

O.N.D. Ezeadubu

Date: 27/11/82.....

Dedicated to my late mother

'Caroline Ezeadubu'

ABSTRACT

This investigative research consists of three parts: Plotting of theoretical propagation curves with the aid of computer, determining the effect of the variation of the ground conductivity on ground-wave field strength and deduction of the ground conductivity.

Theoretical ground-wave propagation curves were plotted for flat earth with the aid of a digital computer for some broadcast frequencies in use in the Northern States of Nigeria, Computer CALCOMP programmes were developed for the plots.

The effect of the variation of the ground conductivity on ground-wave field strength was investigated by measuring the field strength radiated from MW radio stations for five months, March - July, 1981. The measurements showed that the radiated field strength was practically constant irrespective of whether it was rainy or dry season. One of the conclusions from the measurements was that as the variation of the ground conductivity and vegetation have opposite effect on ground wave the effective influence of the variation of ground conductivity could be so small that it could not be detected with the field strength meter. The field strength increases with increase in the ground conductivity while vegetation attenuates ground wave.

The determination of the ground conductivity in the northern parts of Nigeria was carried out by the attenuation technique. The ground resistivity method was used in Samaru - Zaria to confirm the result obtained there by the

attenuation technique. According to the research results, 2, 3» and 4 mmho/m were obtained as the ground conductivities in parts of Kaduna State; 3 mmho/m was obtained in Kano State; 2 mmho/m was the value obtained in Niger State. 3 and 4 mmho/m were obtained in Sokoto State. A CALCOMP programme was used in plotting the measured field strength on the theoretical propagation curves.

All the CALCOMP programmes used in this research can be found in the Users' Manual of the CALCOMP Programmes for Plotting Theoretical Ground-Wave Propagation Curves written by the author.

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CHAPTER ONE

INTRODUCTION

The International Radio Consultative Committee (C.C.I.R.) and other institutions have published and recommended a lot of data concerning radio wave propagation results and their applications in planning transmission networks. These results have been based on theoretical and experimental considerations, and are used to forecast field strengths in different types of terrain. The recommended theoretical results do not include the influence and effect of the tropospheric refractions and temporal variations of the radio waves. The empirical results are based on measurements conducted in an environment different from ours. There is, therefore, the need to conduct field measurements at both medium and short wave frequencies to determine our environmental effect on them.

For the effective planning and design of MW transmission networks in Nigeria the design engineer requires to know certain environmental factors, including the ground constants - the ground conductivity and the dielectric constant, along the propagation paths. At broadcast and lower frequencies the earth is considered to be purely resistive so that the effect of the ground conductivity (σ) on ground wave propagation out-weighs that of the dielectric constant (ε). The result is the attenuation of the ground wave by the ground as it propagates near the surface of the earth. Therefore, extensive measurements of the ground conductivity to cover the entire broadcasting links in Nigeria are essential if effective

broadcast services are to be realised. The design engineer, also, requires to know our environmental effect on the radiated field strength. Being equipped with knowledge of the temporal variations of the groundwave field strength radiated from the MW transmitters enables effective radio links to be designed in the face of noise and other forms of interference.

The International Telecommunications Union proposed that the majority of the northern parts of Nigeria has a ground conductivity of 3 mmho/m. Around 1969 the personnel of the Radio Television, Kaduna conducted some field measurements with a field strength meter of the radiations from this radio station transmitting at 593 kHz. The measurements were taken at some locations near Kaduna. Assuming 3 mmho/m as the average ground conductivity the theoretical field strength values were obtained from the theoretical propagation curves. The theoretical field strengths were found to agree well with the measured field strengths. However, it was found that in some areas around Kafanchan, Abuja and Jagindi towards the south the measured field strength deviated much from theoretical expectation. This implies that the ground conductivity in these areas might be less than 3 mmho/m. Ajayi could not verify whether the ground conductivity was 3 mmho/m or not in these areas in his 1969 M.Sc. work because a field strength meter was not available at that time.

Other efforts were made in the past towards providing good communication in Nigeria. For example, the first National Symposium on Broadcasting in Nigeria was held at

the University of Ife, Ile-Ife in September, 1978 out of the desire of the members of the Nigeria Association of Planetary and Radio Sciences (NAPRS) to focus attention on broadcasting in Nigeria. A number of papers were presented in the symposium, but only some could be mentioned here. In his paper, Kolawole highlighted high-frequency prediction techniques and the problems of radio communication at low latitudes and methods of overcoming them. The requirements of a Broadcasting Satellite system were discussed by Iyengar, and Mohammed discussed the Broadcasting Aspects of Telecommunication system in Nigeria, including the tethered aerostats (balloons) as a revolutionary technique in communication. Oyinloye reviewed radio propagation studies in Nigeria in the past and the applications of the results to communication in the different wavebands. His paper centred around the characteristics of the media for ground, tropospheric and ionospheric waves and the incidence and noise power of atmospheric radio noise. Owolabi discussed some engineering design factors essential for an efficient and reliable performance of a medium wave broadcasting system. A simple method of analysis of the field strength data to obtain ionospheric absorption was presented by Ajayi.

This project is, therefore, motivated by the desire to provide further information for designing effective radio links in Nigeria. This is to add to the efforts which have been and are being made by other people towards the achievement of good communication in Nigeria. In this work the author addressed himself to the following tasks:

(1) To highlight the various methods of measuring the ground conductivity and to plot theoretical ground-wave propagation curves for the broadcast frequencies being used in broadcast services in the Northern States of Nigeria and to develop a computer programme for plotting the curves.

(2) To investigate the effect of the variation of ground conductivity on ground-wave field strength. Measurements of the temporal variations of the ground-wave field strength radiated from the following radio stations:

- Rima Radio, Sokoto (558 kHz)
- Radio Kano, Kano (729 kHz)
- Radio Niger, Minna (702 kHz)
- Federal Radio Corporation of Nigeria (F.R.C.N.), Kaduna (593 kHz)

as a means of investigating the effect of the variation of ground conductivity on ground-wave field strength.

(3) To determine the ground conductivity in the northern parts of Nigeria using the ground-wave attenuation and resistivity methods.

Medium-wave propagation curves are essential tools for evaluating optimum radiated power condition for a given coverage area of a radio station provided the electric parameters (σ) and (ϵ) are known. Theoretical propagation curves at medium-wave broadcast frequencies are plotted for a range of ground conductivity on a digital computer installed at the Computer Centre of the Ahmadu Bello University, Zaria.

The ground constants (σ, ε) may increase in their values as the moisture content of the ground increases. Therefore, one may expect the received ground-wave field strength to increase with the values of (σ) and (ε). Whether this statement is valid or not will depend on the results of measuring the temporal variations of the ground-wave field strength radiated from the radio stations of interest in this research. The equipment used in the measurements comprised a Rohde and Schwarz field strength meter, a Hewlett-Packard strip chart recorder - 7100B and an a.c. voltage stabilizer. This equipment is installed in the departmental radio research hut at Samaru in Zaria, Nigeria in equatorial Africa (latitude 11° 11' and longitude 7° 35')[1]. The measurements were conducted from March - July, 1981.

To determine the ground conductivity in various directions in the northern part of Nigeria by the ground-wave attenuation method measurements were taken of the ground-wave field strength radiated from

- Rima Radio, Sokoto
- FRCN, Kaduna
- Radio Niger, Minna
- Radio Kano, Kano

with a portable field strength meter, FIM - 21 manufactured by Potomac Instruments Inc. By comparing the results of ground-wave attenuation technique with the theoretical propagation curves the average ground conductivities in

different directions were deduced. The resistivity method was simply used to confirm the value of the ground conductivity obtained in Samaru, Zaria by the attenuation technique. Wenner arrangement of the probes (electrodes) was adopted in the resistivity method. The cross-checking of the results obtained by the attenuation method could only be effected in Samaru (Zaria) owing to lack of time.

CHAPTER TWO

THE GROUND CONDUCTIVITY AND PLOTTING OF THEORETICAL PROPAGATION CURVES

2.1 Methods of Measuring Ground Conductivity

The International Radio Consultative Committee (C.C.I.R.) has recommended various methods of measuring the ground conductivity.[2] However, the methods are not equally precise and they do not suit the same circumstances. The methods are:

(i) The soil sample method
(ii) The ground resistivity method
(iii) The wave - tilt method
(iv) The ground-wave attenuation method
(v) The attenuation with depth below the surface method
(vi) The phase change method
(vii) The dispersion method
(viii) The reflection coefficient method.

(i) The Soil sample method

The electric parameters - conductivity and dielectric constant of soil samples may be determined by measuring the resistance and reactance of capacitor units with soil as their dielectric. This method may be used in the frequency range, 1 kHz to 10 MHz and is more suited to investigating any variations in the constants and the parameters on which they depend.

(ii) The ground resistivity method

This method consists of measuring the resistance between probes driven into the ground. A direct current is passed between one pair of the probes and the resultant potential difference is measured between the other pair. It is a simple and convenient method.

(iii) The wave-tilt method

Surface losses give rise to elliptically polarized electric force vector with the major axis tilted forward to account for the flow of power into the surface. The axial ratio and forward tilt of the ellipse are carefully measured with a rotable dipole. The measurement of the forward tilt should be made relative to the local normal to the surface if the surface is not horizontal. Careful use of this method allows measurement of earth constants over a range of frequencies from 100 kHz to 40 MHz.

Near regions of large gradient of conductivity or in the vicinity of surface or buried objects of high conductivity the measurements will be erroneous. This method takes account of the general structure of the ground around the point of measurement and yields the effective constants of the earth for a given frequency.

(iv) The ground-wave attenuation method

In this method measurements are made of the attenuation with distance of the field strength radiated from a transmitter. By comparing the results with the theoretical

propagation curves derived according to rigorous theories or semi-empirical methods enables the ground conductivity to be deduced. This method is comprehensive as it takes all factors into consideration. It enables the variations of earth constants along the propagation path to be deduced. However, it may not yield results as accurate as the ground resistivity or the wave-tilt methods.

(v) The attenuation with depth below the surface method

The ground conductivity can also be determined by measuring the relative rate of attenuation of the field strength as a receiver is lowered in a well or other suitable hole in the earth.

(vi) The phase change method

By measuring the change of phase of a ground-wave with distance the conductivity over homogeneous ground may be deduced. The conductivity is deduced from the rate of change of the phase. This method is very effective in locating discontinuities in the ground and has been applied only at low frequencies.

The disadvantage of this method is that it requires an auxiliary VHF or UHF link to provide a reference for phase at the receiver.

(vii) The dispersion method

When an impulse, such as that resulting from lightning strokes, is propagated over the surface of the earth, the wave shape is changed. That is, the pulse is dispersed as

the wave propagates over the surface. The degree of the dispersion depends on the ground conductivity. Two points in line with the source are chosen, one fairly close to the source, and the other remote, where the wave shape is measured. The observed change in wave shape can be related to the calculated dispersion according to the ground conductivity values in an equivalent homogeneous earth.

This method is suitable for relatively long paths and low frequencies. Though it enjoys the advantage that no transmitter is required, it, however, suffers some setbacks. This is because data can only be accumulated very slowly due to random and infrequent occurrence of suitable lightning strokes. Also it requires complicated equipment and involves complex mathematics.

(viii) The reflection coefficient method

This method involves measuring the reflection coefficient of the ground in the field by methods involving normal incidence radiation. From the results, the ground conductivity and the dielectric constant of the ground may be obtained. The method is suitable at high frequencies.

Application of the Attenuation and Resistivity Methods

Of the several methods discussed above the ground-wave attenuation and resistivity methods have been applied in this work. This is because of the convenience of the attenuation method in determining the variation of the ground conductivity along a given path fairly accurately and

a field strength meter was available. The resistivity method was used because it gives an accurate value. Thus, results of the two methods may be compared. The two methods have been discussed fully in chapter 4.

2.2 Theoretical Ground-Wave Propagation Curves

Theoretical propagation curves are curves of computed electric field strength normalized to the effective radiated power of 1 kW plotted against distance from the transmitting antenna. They are based on the rigorous mathematical treatment of Norton.[3]

Ajayi and Owolabi[4] have prepared theoretical MW propagation curves for use in planning and designing transmission networks in Nigeria. Their research results showed that the determination of the dielectric constant (ϵ) is not crucial. They used a range of $\epsilon = 4$ to 15 and showed that the field strength is not significantly affected by this variation. The C.C.I.R. has adopted $\epsilon = 4$ as representative of an average soil.

According to Dolukhanov[5] the ground wave may be defined thus,

> "A radio wave propagated close to the earth's surface and partly following the curvature of the globe due to diffraction is called a ground or surface wave".

For vertically polarized antennae the received field strength will be surface wave only. Ground-waves are propagated close

to the earth's surface and, therefore, suffer varying amounts of attenuation depending on its nature - surface irregularities, dielectric constant and ground conductivity. As such the electrical characteristics of the earth's surface must be considered in designing a radio link (or a radio circuit).

2.3 *The Ground Constants In Propagation Problems*

Ground waves are vertically polarized, since any horizontal component of electric field in contact with the earth is short-circuited by the earth. The ground wave is considered to induce charges in the earth as it propagates along, which travel with the wave constituting a current. The earth is considered to behave as a leaky capacitor which may be represented by a resistance (or conductance) shunted by a capacitive reactance. Since we speak of the relative permittivity (or dielectric constant) of the dielectric of a capacitor, as a leaky capacitor the earth may be described in terms of conductivity, σ and dielectric constant, ε. Another parameter of the earth is relative permeability.

The dielectric constant and conductivity of the earth are related to the complex relative permittivity, ε' relative to a vacuum by the following expression:

$$\varepsilon' = \varepsilon - j60\sigma\lambda$$

where σ is in mmho/m,

λ is the free-space wavelength in metres,

and the time factor $\exp(j\omega t)$ is assumed.

The displacement and conduction current densities are in the ratio,

$$\varepsilon : 60\sigma\lambda$$

Thus, at broadcast and lower frequencies to a first approximation the earth can be regarded as purely resistive. That is, the effect of conductivity is predominant. The permeability of the earth is taken as that of free-space since it is considered to be non-magnetic at MW broadcast frequencies. The relative permeability is, therefore, unity.

2.4 Analysis of Ground-Wave Propagation

The mathematical analysis to be presented here for the calculation of ground-wave field strength was proposed by Norton. Owolabi[6] also has considered some design aspects of a MW broadcasting system.

At MW broadcast frequencies the transmitting antennae are usually vertical radiators less than $\lambda/4$ in height and the broadcast frequency is less than 3 MHz. Vertical polarisation has a superior ground-wave and sky-wave propagation characteristics than horizontal polarization. Vertical radiators, in addition, produce maximum radiation in the horizontal plane, which increases with the height of the radiator up to approximately $(5/8)\lambda$.

Assuming that both the transmitter and the receiver are on the ground, height-gain effects can be ignored in estimating the electric field intensity in medium-wave transmission. The

curvature of the earth is entirely negligible if the distance D from the transmitter satisfies the relation

$$D \leq 80/f^{\frac{1}{3}}$$

where f is the frequency in MHz,

D is in kilometres.

However, no serious error is introduced until the distance exceeds twice this value.(7) The reduction in field strength value below the free-space value at a greater distance than this tends to be more as a result of the earth curvature than as a result of the ground losses. The effects of refraction and diffraction of radio waves in the earth's atmosphere are considered in such a case.

Assuming a flat earth the ground-wave field strength, E can be written in the form,

$$E = AEo/D \ (mV/m) \qquad \ldots\ldots \qquad (2.1)$$

where Eo is the field strength at the surface of the earth at a unit distance from the transmitting antenna, neglecting earth's losses,

D is the distance from the transmitting antenna in kilometres, and

A is the factor that considers the ground losses.

The field strength, Eo depends upon the radiated power and the directivity of the antenna in the horizontal and vertical planes. When the antenna is omnidirectional in the

horizontal plane and produces a radiated field proportional to the cosine of the angle of elevation (i.e. short vertical antenna) the expression for Eo at a distance of 1 km can be written in the form,

$$Eo = 300\ p^{\frac{1}{2}}\ (mV/m) \qquad \ldots\ldots \qquad 2.2$$

where p is the effective radiated power in kW.

The factor, A may be estimated from the following expression,

$$A \sim \frac{2 + 0.3P}{2 + p + 0.6p^2} - (\sin b)\ (p/2)^{\frac{1}{2}} \exp\ (-5p/\theta)\ \text{(no unit)} \qquad \ldots\ldots \qquad 2.3$$

where p is a numerical distance given by,

$$p = \frac{\pi d \cos^2 b''}{R \lambda \cos b'}\ \text{(no unit)} \qquad \ldots\ldots \qquad 2.4$$

where $$b' = \tan^{-1} \frac{\epsilon - 1}{R} \qquad \ldots\ldots \qquad 2.5$$

$$b'' = \tan^{-1} \frac{\epsilon}{R} \qquad \ldots\ldots \qquad 2.6$$

$$b = 2b'' - b' \qquad \ldots\ldots \qquad 2.7$$

$$R = \frac{18\sigma}{f} \qquad \ldots\ldots \qquad 2.8$$

where b is the phase constant,

f is the frequency in MHz

ϵ is the dielectric constant of the ground referred to air as unity

d is in metres (distance from the transmitting antenna) an

σ is the ground conductivity in mmho/m.

The electric parameters (σ, ϵ) are the parameters within the coverage area of the transmitter. Equations (2.1) to (2.8) are essential in evaluating the electric field strength at a given distance from the transmitter for given values of ϵ, σ, p and f as a first step in plotting the theoretical ground-wave propagation curves. A computer programme may be developed to do the plots.

2.5 Development of CALCOMP Plot Programmes for Plotting The Theoretical Propagation Curves (8,9)

Based on equations (2.1) to (2.8) FORTRAN IV CALCOMP Plot programmes were developed in this work for plotting the theoretical ground-wave propagation curves. The CALCOMP plot programmes are indicated in appendices 1 and 2. A separate manual was established in this work for plotting the theoretical curves. In the computation of the field strength the distance from the transmitter takes values from 5 to 200 km in steps of 1 km, and the conductivity of the ground assumes values from 1 to 20 mmho/m in steps of 1 mmho/m, and the relative permittivity of the ground is taken as 4 throughout.

The computed electric field strength is in dB referred to 1 micro-volt per metre. The computation of the field strength as well as the plotting of the theoretical propagation curves were done with the aid of the digital computer, model CY 72 manufactured by the Control Data Corporation, U.S.A. The curves are indicated in appendix 3 and are presented for the broadcast frequencies shown in table 2.1.

It is to be noted that the attenuation of the ground wave by surface objects - vegetation, building, and other structures have been ignored in the analysis. The attenuation of ground wave by such surface objects is normally taken care of in the design of radio links by using an equivalent surface with electric parameters (σ, ϵ) which will produce the same amount of attenuation as the actual surface in a specific band of frequencies.

TABLE 2.1

TRANSMITTING STATIONS	FREQUENCY OF TRANSMISSION	EFFECTIVE RADIATED POWER
1. Radio Benue Makurdi	693 kHz	10kW
2. Radio Borno, Maiduguri	1397 kHz	1 x 250 W 2 x 25 kW
3. Gongola State Radio, Yola	1017 kHz	10 kW
4. Federal Radio Corp. of Nigeria, (F.R.C.N.) Kaduna	592 kHz 1107 kHz	10 kW 25 kW
5. Radio Kano, Kano	729 kHz	2 x 25 kW
6. Radio Niger, Minna	702 kHz	10 kW
7. Plateau State Radio, Jos	1313 kHz	9.56 kW
8. Rima Radio, Sokoto	558 kHz	2 x 25 kW
9. Kaduna State Radio, Kaduna	639 kHz	--

2.6 Applications of The Theoretical Ground-Wave Propagation Curves

A design engineer is normally interested in the average ground conductivity, the relative permittivity, and the relative permeability along a propagation path. He is equally interested in the coverage area of the primary, secondary, and fringe service areas, and in the effective radiated power of a broadcasting transmitter.

If the broadcasting frequency and the relative permittivity of the ground are known theoretical propagation curves may be used in deducing the average ground conductivity along the propagation paths by the ground-wave attenuation technique. The subject is treated in chapter 4. The coverage area and the effective radiated power of a radio station may also be deduced from the propagation curves if the appropriate curve is used.

2.7 The Effect of The Curvature of The Earth

At large distances from the transmitting antenna, the reduction in field strength value below the free space value tends to be more as a result of the earth curvature than as a result of ground losses. Surface waves reach distant points of reception by a process of bending around the curved surface of the earth, that is, by diffraction and refraction in the earth's atmosphere. The effects of diffraction and refraction, therefore, have to be considered at large distances. Norton[3] has presented the solutions for the field strengths at large distances in graphical forms to make the calculations less cumbersome.

The effect of air refraction in the lower atmosphere can be included in the calculations by using the effective radius of the earth which is Ka, where a is the actual radius of the earth. Assuming that the change of the refractive index with height above the earth is constant at $^{dn}/_{dh}$, then K is given by

$$K = 1/(1 + \frac{a}{n} \cdot \frac{dn}{dh})$$

where a is the actual radius of the earth and in the same units as the height, h; n is the refractive index. On the average K has a value of about 4/3, but this value varies due to variations in the gradient of the dielectric constant of air with weather changes.

The final step is to draw in a smooth curve between the curve realized for short distances by the plane-earth method and the propagation curve realized by calculations which consider the effect of the curvature of the earth. This final propagation curve shows the field intensity versus distance.

It will be worthwhile to examine the level of agreement between the theoretical curves obtained for flat earth by using equations (2.1) to (2.8) and the C.C.I.R. curves obtained taking into account the effect of the curvature of the earth which are to be found elsewhere.[2] Consider the C.C.I.R. propagation curve for 700 kHz, σ = 3 mmho/m, and ε = 4 which is shown in the reference and the propagation curve plotted in this project for flat earth for

Radio Niger, Minna (702 kHz) for the same ground constants. Comparison of the two curves is facilitated by getting the field strengths for the following distances, 8, 24, 40, 50, 80, 120, 160 and 200 km from the curves. The results are indicated in table 2.2. From 8 - 120 km, the field strength is almost the same, it is only at 120 km that the difference is 1 dB. Then, above 120 km the difference between the field strength interpolated from the two curves for corresponding distance increases from 1 dB to 3.8 dB at 200 km. This confirms the statement that the effect of the earth curvature is fairly negligible up to a certain distance, according to equation (4.2), refer to table 4.1 for additional information.

TABLE 2.2

σ = 3 mmho/m

ε = 4

Distance from Transmitter (km)	8	24	40	50	80	120	160	200
Field Strength from normalized propagation curve for flat earth f = 702 kHz	88.3 dB	72.7 dB	64.0 dB	59.8 dB	51.1 dB	43.5 dB	37.8 dB	33.8 dB
Field Strength from normalized propagation curve considering effect of earth curvature (C.C.I.R. Curve) f = 700 kHz	88.3 dB	72.5 dB	64.0 dB	60.0 dB	51.0 dB	42.5 dB	35.0 dB	30.0 dB

NB: The field strengths are indicated with reference to 1 micro-volt/m.

CHAPTER THREE

THE EFFECT OF THE VARIATION OF GROUND CONDUCTIVITY ON GROUND-WAVE FIELD STRENGTH

3.1 Introduction

Radio propagation studies have been going on in Nigeria for the past 20 to 25 years and the results obtained are applied to communications in the different wave bands for improved communication services[10]. Temporal variations of ground-wave field strength have equally attracted some research work. For instance, two final year students, Badmos[11] and Pindar[12] undertook studies of temporal variations of ground wave field strength at Samaru in Zaria. Both of them arrived at the conclusion that the ground-wave field strength does not vary with time of the day which is in agreement with theoretical prediction.

The effect of the variation of ground conductivity on ground-wave field strength may be studied by taking measurements of the temporal variations of the ground-wave field strength with a field strength meter. The change of the field strength from hour to hour, day to day, or from month to month may then be visualized and correlated with meteorological data.

3.2 Factors Influencing The Effective Ground Constants[2]

The effective ground constants are determined by the following factors:

(1) The nature of the soil - which is due to its ability to absorb and retain moisture.

(2) The moisture content - laboratory measurements show that the ground constants (ground conductivity and dielectric constant) increase in their values as the moisture content increases. This may be the major factor determining the electrical constants of the earth.

(3) The temperature - temperature effects are likely to be important only at high frequencies where the penetration of the waves is small, or if the ground is frozen to a good depth. Generally, there is a large decrease in the constants (conductivity and dielectric constant) at freezing point.

(4) The frequency - laboratory measurements show that there is a change of the constants (ground conductivity and dielectric constant) with frequency which greatly depends on the moisture content. This variation is clearly defined above 1 GHz.

(5) The general geological structure - the ground over which the wave propagates is not usually homogeneous so that the effective ground constants are determined by the nature of the surface soils and that of the underlying strata.

(6) The penetration and spread of waves - the depth of penetration and spread of waves also influence the effective earth constants.

(7) The energy absorbed by surface objects - surface objects do not have a direct influence on the ground constants;

they simply contribute to the attenuation of ground waves. For design purposes the effect of such losses are accounted for by using an equivalent surface with the appropriate ground constants in propagation calculations.

3.3 Measurements of Temporal Variations of Ground-Wave Field Strength

The variation of the ground conductivity may be expected to affect the ground-wave field strength. It is intended in this part of the research to investigate this. The field strength of radio waves radiated from the following radio stations was to be measured:

Rima Radio, Sokoto (557 kHz)[1]
FRCN, Kaduna (593 kHz)
Radio Niger, Minna (702 kHz)
Radio Kano, Kano (728 kHz)[2]

The radio stations were alternately monitored from day to day with a Rohde - Schwarz field strength meter. A continuous recording of the radiated field strength was made with a Hewlett-Packard strip chart recorder - 7100B and a Servomex a.c. voltage stabilizer was used. A full description of the equipment used is indicated elsewhere.(13,14,15) The field strength radiated from Rima Road, Sokoto was measured from March to July, 1981 and April to July for the remaining radio stations. The hourly, daily and monthly medians[3] of the field strength in dB (reference 1 micro-volt/m) are presented

in tables 3.1, 3.2 and 3.3. The corresponding graphs are indicated in figs. 3.1, 3.2, and 3.3. Interpretations are given in sections 3.8, 3.9, 3.10 and 3.11. The accuracy of indication of the meter (in the linear range) with rod antenna is better than $\pm$ 2 dB.

Some problems were encountered during the recordings. No measurements were taken in January and February as a result of the break down of the field strength meter. In addition, when the meter was finally repaired and measurements commenced in March the strip chart recorder was put out of use by the cutting of its motor belt due to wear and tear. A change to another type of chart recorder manufactured by Hewlett-Packard left me operating with a limited recording paper. Thus, measurements were deliberately put off on certain days of the month. A replacement order was, however, placed for the cut belt but it took some time to arrive from England. Another factor that interferred with the measurements was lightning and rain storm compelling recordings to be put off from time to time.

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1 557 kHz was the previous transmission frequency of Rima Radio, Sokoto before it was changed to 558 kHz to avoid interference from adjacent stations in August 1981.

2 728 kHz (Radio Kano) was also changed to 729 kHz for the same reason in August 1981.

3 The medians were computed with the aid of the digital computer(8).

TABLE 3.1

HOURLY MEDIANS OF FIELD STRENGTH IN DB (ABOVE 1 MICRO-VOLT/M)

YEAR OF RECORDINGS: 1981.

LOCAL TIME	(HOURS)	0700	0800	0900	1000	1100	1200	1300	1400	1500
RIMA RADIO	MARCH	46.5	43.7	43.3	43.3	42.8	43.3	42.6	42.3	43.2
SOKOTO	APRIL	42.1	42.0	42.1	42.4	42.1	42.2	42.1	42.4	42.5
(557 kHz)	MAY	43.2	43.2	43.5	43.6	43.7	43.7	43.1	43.2	42.6
	JUNE	43.0	42.5	42.5	42.5	42.5	42.6	42.6	43.3	43.6
	JULY	42.4	42.1	42.1	42.4	42.6	42.6	42.6	43.1	43.2
FRCN KADUNA	APRIL	76.8	76.8	76.9	77.0	77.0	77.0	77.0	77.0	76.7
(593 kHz)	MAY	75.8	75.8	75.9	76.0	76.1	76.1	76.1	76.1	76.1
	JUNE	75.5	75.8	75.8	75.8	75.8	75.9	75.9	75.9	76.1
	JULY	76.1	76.3	76.6	76.8	76.6	76.8	76.8	76.8	77.1
RADIO NIGER	JUNE	34.5	37.5	38.3	38.3	41.1	40.5	40.0	39.1	38.2
MINNA										
(702 kHz)	JULY	38.0	38.6	39.5	40.0	40.0	39.5	39.3	39.5	41.6
RADIO KANO	APRIL	57.5	57.5	57.3	57.4	57.6	57.4	57.5	57.5	57.3
KANO	MAY	56.7	56.8	56.6	57.4	56.8	56.6	57.1	56.3	56.8
(728 kHz)	JUNE	56.5	56.5	57.0	57.2	57.4	57.0	57.0	57.5	57.5
	JULY	55.8	55.8	55.8	56.7	57.6	56.1	55.6	55.3	55.0

TABLE 3.1 (Continued)

HOURLY MEDIANS OF FIELD STRENGTH IN DB (ABOVE 1 MICRO-VOLT/M)

YEAR OF RECORDINGS: 1981

LOCAL TIME	(HOURS)	1600	1700	1800	1900	2000	2100	2200
RIMA RADIO	MARCH	43.1	43.1	43.1	42.9	43.2	47.0	52.3
SOKOTO	APRIL	42.5	42.4	42.7	42.9	41.6	42.6	43.8
(557 kHz)	MAY	42.4	42.6	43.0	41.9	44.5	46.3	45.3
	JUNE	43.2	42.7	42.7	42.7	42.3	44.9	47.8
	JULY	43.2	43.2	44.2	44.4	42.4	43.6	46.2
FRCN KADUNA	APRIL	77.0	77.2	77.2	77.2	77.1	77.1	77.1
(593 kHz)	MAY	76.0	76.6	76.3	76.3	76.4	76.4	76.7
	JUNE	75.9	75.8	76.0	75.9	76.0	76.0	76.0
	JULY	76.8	76.7	76.7	76.7	76.7	76.7	76.7
RADIO NIGER	JUNE	37.9	39.1	38.9	38.9	40.9	42.6	44.6
MINNA	JULY	41.6	41.6	41.9	41.9	42.7	44.0	43.4
(702 kHz)								
RADIO KANO	APRIL	58.1	57.8	57.8	57.8	57.8	57.6	57.7
KANO	MAY	57.8	57.1	57.3	56.5	57.9	56.5	56.5
(728 kHz)	JUNE	57.5	57.4	57.5	57.3	56.9	57.0	56.6
	JULY	55.7	55.7	56.0	54.5	53.7	54.5	52.9

TABLE 3.2

DAILY MEDIANS OF FIELD STRENGTH IN DB

(ABOVE 1 MICRO-VOLT/M)

	DAYS OF RECORDING	10/3/81	17/3/81	..	-	-	-
	FIELD STRENGTH	42.7	43.4				
RIMA RADIO	"	1/4/81	7/4/81	14/4/81	18/4/81	25/4/81	27/4/81
	"	42.7	41.8	42.3	41.5	42.1	42.3
SOKOTO	"	2/5/81	6/5/81	8/5/81	31/5/81	-	-
(557 kHz)		42.6	43.7	43.8	42.1		
	"	11/6/81	12/6/81	21/6/81	22/6/81	30/6/81	-
		42.5	42.5	43.9	43.3	42.3	
	"	1/7/81	14/7/81	15/7/81			
		42.3	42.6	43.5	-	-	-
	"	3/4/81	6/4/81	9/4/81	17/4/81	22/4/81	30/4/81
		76.3	76.8	77.4	77.1	76.8	76.1
FRCN KADUNA	"	9/5/81	15/5/81	31/5/81			
(593 kHz)		76.1	76.3	76.1	-	-	-
	"	3/6/81	15/6/81	25/6/81	26/6/81		
		76.2	75.5	76.0	76.2	-	-
	"	29/7/81	30/7/81	31/7/81			
		76.5	76.8	76.8	-	-	-
	"	24/6/81	28/6/81	29/6/81			
		39.1	41.0	41.8	-	-	-
RADIO NIGER	"						
MINNA		17/7/81	18/7/81	20/7/81			
(702 kHz)		41.7	39.5	41.6	-	-	-

Table 3.2(Contd)

DAILY MEDIANS OF FIELD STRENGTH IN dB (ABOVE 1 uV/m)

RADIO KANO KANO (728 kHz)	"	10/4/81 57.3	11/4/81 57.9	13/4/81 57.6	20/4/81 57.4	28/4/81 57.8	29/4/81 57.3
	"	11/5/81 58.1	25/5/81 56.8	30/5/81 56.4	31/5/81 56.8	-	-
	"	2/6/81 57.4	16/6/81 57.3	17/6/81 57.1	18/6/81 57.0	-	-
	"	22/7/81 56.0	24/7/81 55.6	25/7/81 55.6	-	-	-

TABLE 3.3

MONTHLY MEDIANS OF FIELD STRENGTH IN dB (ABOVE 1 uV/m)

YEAR OF RECORDINGS: 1981

RIMA RADIO SOKOTO (557 kHz)	MARCH	43.2
	APRIL	42.4
	MAY	43.2
	JUNE	42.7
	JULY	42.7
FRCN KADUNA (593 kHz)	APRIL	77.0
	MAY	76.1
	JUNE	75.9
	JULY	76.7
RADIO NIGER NINNA (702 kHz)	JUNE	39.0
	JULY	40.8
RADIO KANO KANO (728 kHz)	APRIL	57.6
	MAY	56.8
	JUNE	57.1
	JULY	55.7

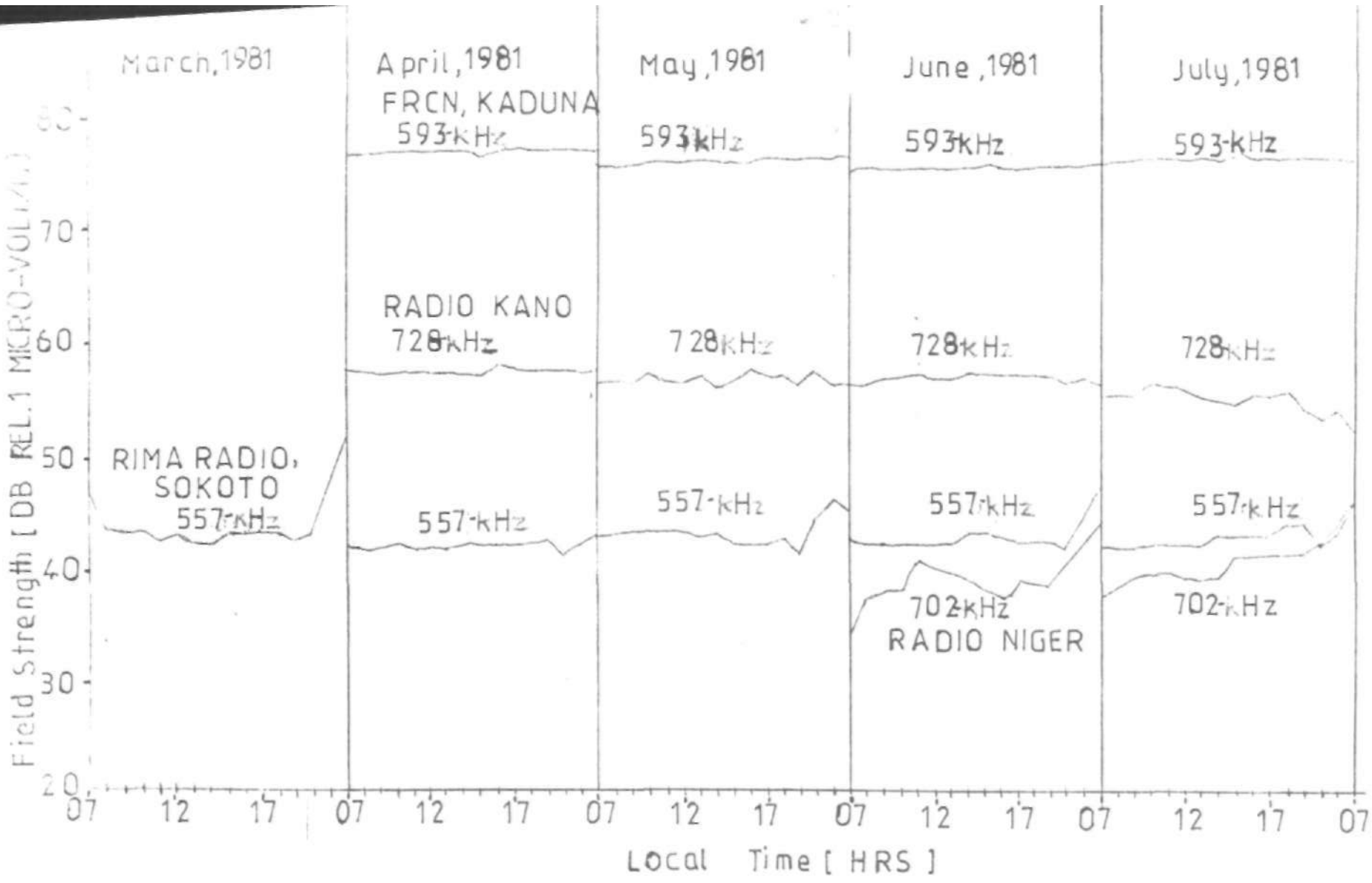


Figure 3-1 ; Hourly variations of ground-wave-field strength in Samaru[Zaria].

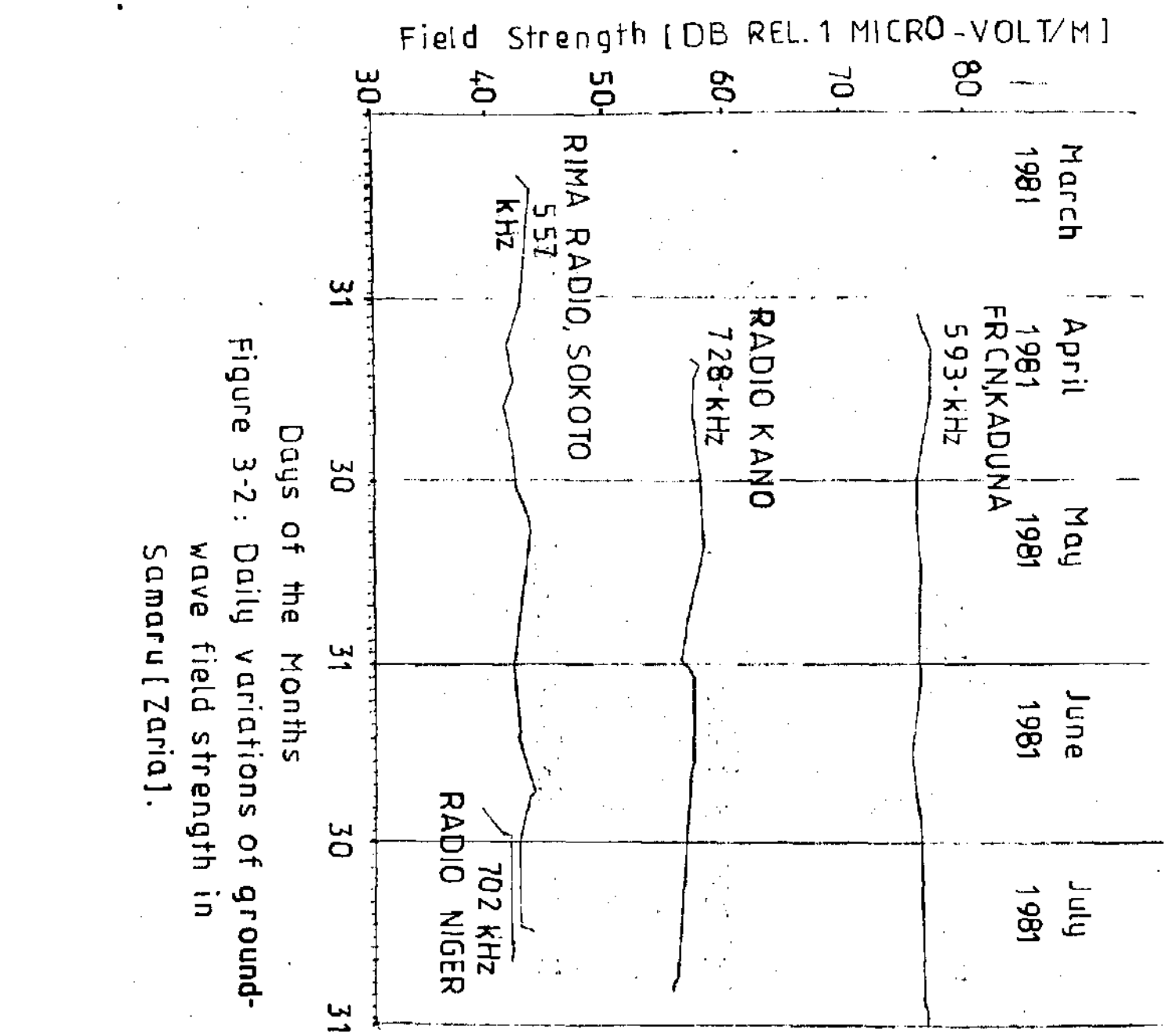


Figure 3-2: Daily variations of ground-wave field strength in Samaru [Zaria].

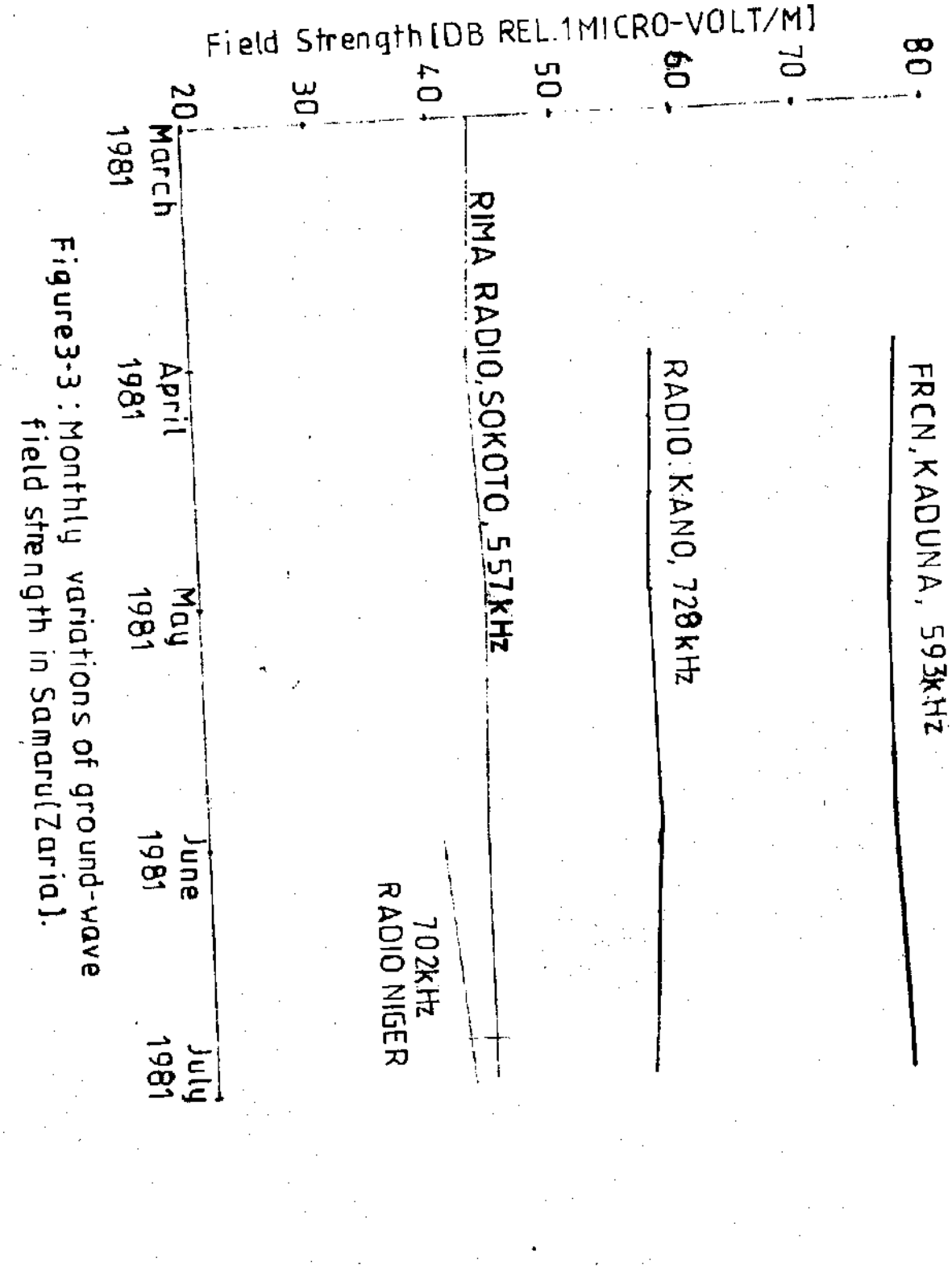


Figure3-3 : Monthly variations of ground-wave field strength in Samaru(Zaria).

3.4 Straight Line Distances of Transmitting Antennae From Samaru

The straight line distances of the transmitting antennae from Samaru, Zaria are presented in table 3.4.

TABLE 3.4

Radio Stations	Transmitter Locations	Distances of Transmitting Antennae From Research Hut in Samaru, Zaria
FRCN Kaduna	Jaji	38 km
Kano Radio	Joganna	154 km
Radio Niger	Metunbi	208 km
Rima Radio Sokoto	Shuni	322 km

3.5 Fading of Radio Signals[5,16]

In the recordings early hours of the day and night-time measurements are characterized by fading, except recordings for the 593 kHz transmitter (FRCN, Kaduna) which is constant at all times as shown in figure 3.4, because it is only 38 km from the monitoring point (lies in the primary service area). Fading occurs because the ground wave and the radio wave reflected from the ionosphere (the sky wave) arrive out of phase or in phase at the receiver. If two waves arrive at a

receiving antenna by different paths the individual signal components of the waves can reinforce or cancel each other depending on the relative phase of the waves. The two waves can add in phase if their path difference is one wavelength or multiples of one wavelength. This results in reinforcement. On the other hand, if the path difference is one-half wavelength or odd multiples of one half-wavelength the waves arrive out of phase at the receiving antenna. This results in a complete cancellation at a given frequency if the waves are of equal amplitude.

Multiple paths of unequal amplitude may add as shown in the following expression:

$$e(t) = A_1 \sin (wt + 2\pi d_1/\lambda) + A_2 \sin (wt + 2\pi d_2/\lambda) + \ldots\ldots + A_n \sin (wt + 2\pi d_n/\lambda)$$

where A_1, A_2, A_n = amplitude of wave

d_1, d_2, d_n = path length

w = $2\pi f$

f = frequency of wave

Wavelength and path length are expressed in the same units. It can be seen from the expression that since wavelength appears in the equation fading due to multipath reception is frequency-dependent. This sort of fading in which different frequency components in a modulated wave fade differently resulting in the distortion of the modulation envelope is called <u>selective fading.</u>

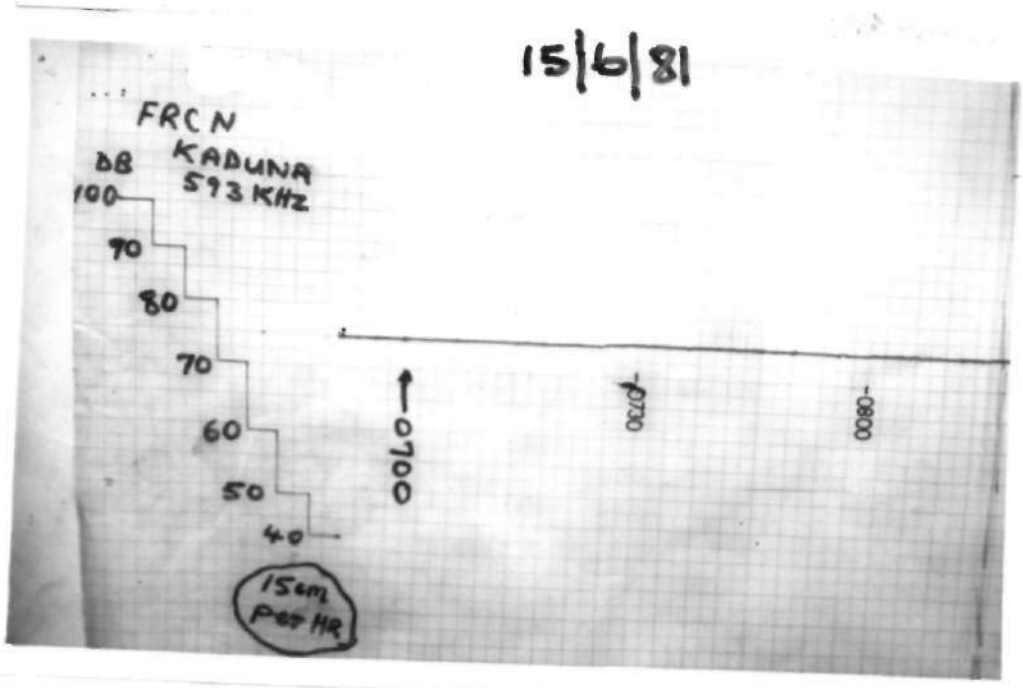
Because the electron density of the ionosphere fluctuates the reflection height is continually changing and so the path length of the sky wave. This causes the relative phase relationship between the ground and the sky waves to vary in a haphazard and unpredictable manner. This leads to similar fluctuations in the amplitude of the resultant signal strength. This kind of fading is known as amplitude fading. A record of fading for the 557 kHz transmitter (Rima Radio, Sokoto) at night is shown in figure 3.5(b). Figure 3.5(a) is the day-time recording for the radio station. Fading is not well pronounced for Radio Kano (728 kHz) as shown in figure 3.6.

If Δr is the change in path length for the sky wave, the corresponding phase change, $\Delta \phi = 2\pi \Delta r / \lambda$. Thus, it is clear that the same change of path length will produce a greater phase change as the wavelength is decreased. It is a fact that shorter wavelengths experience deeper fading but of a shorter duration. This explains why fading is well marked at wavelengths close to the upper limit of the MW band.

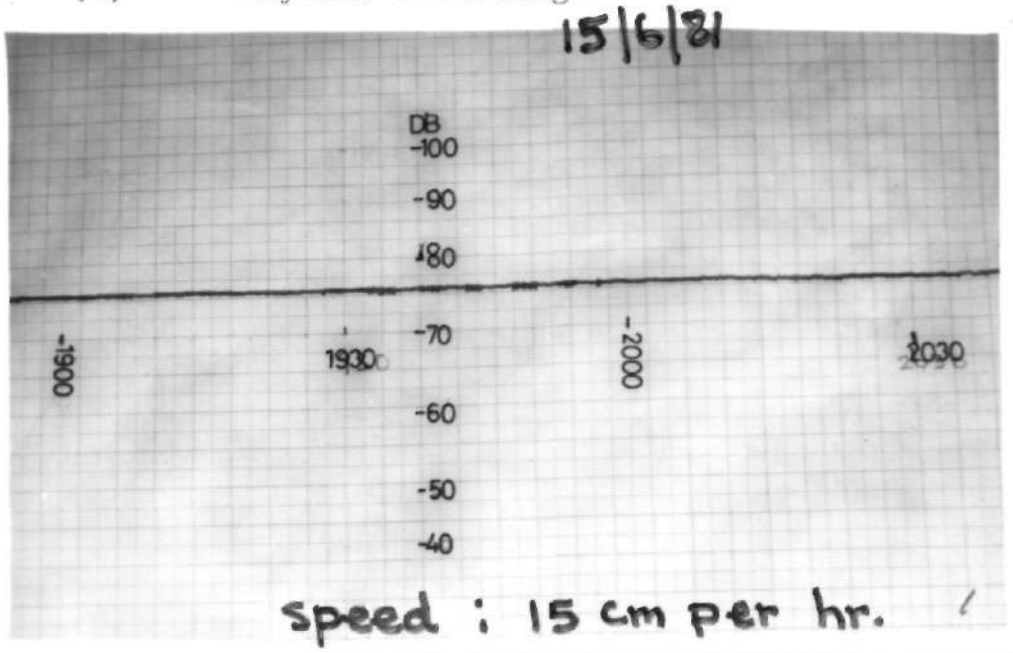
3.6 Diurnal Variations in Signal Strength[5,10,16]

Medium wave band lies between 300 kHz and 3 MHz. Frequencies in this range are used primarily for broadcast purposes.

In the medium-wave band propagation is by ground waves at daytime since the sky waves suffer severe attenuation in the D and E regions. In addition, the transmitting and receiving antennae are vertical radiators usually of height less than a

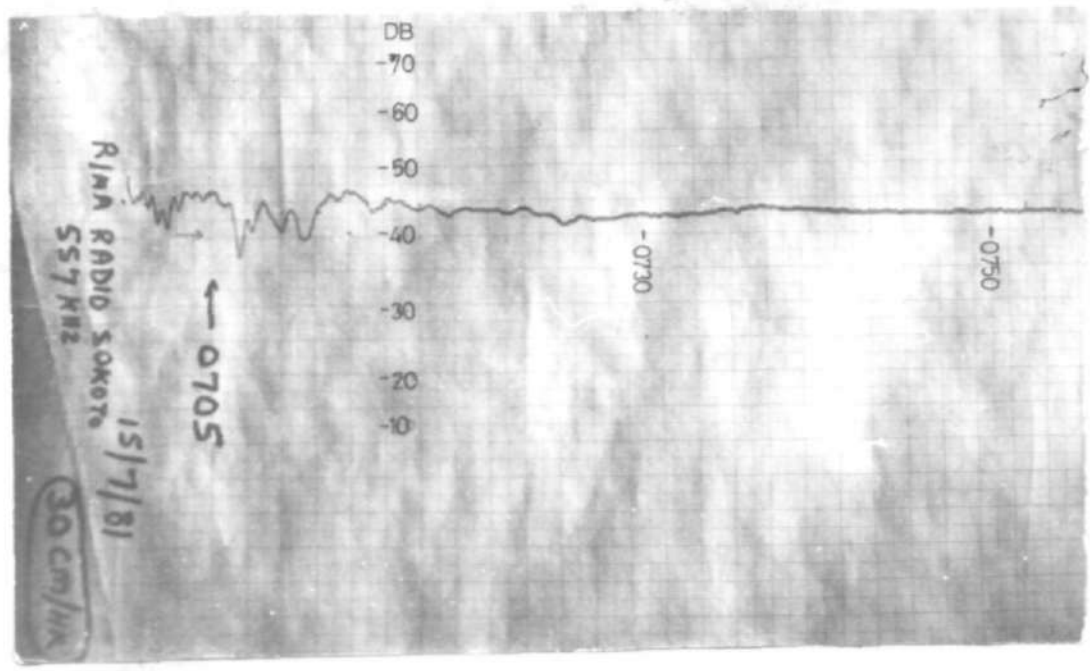


(a) Daytime recording

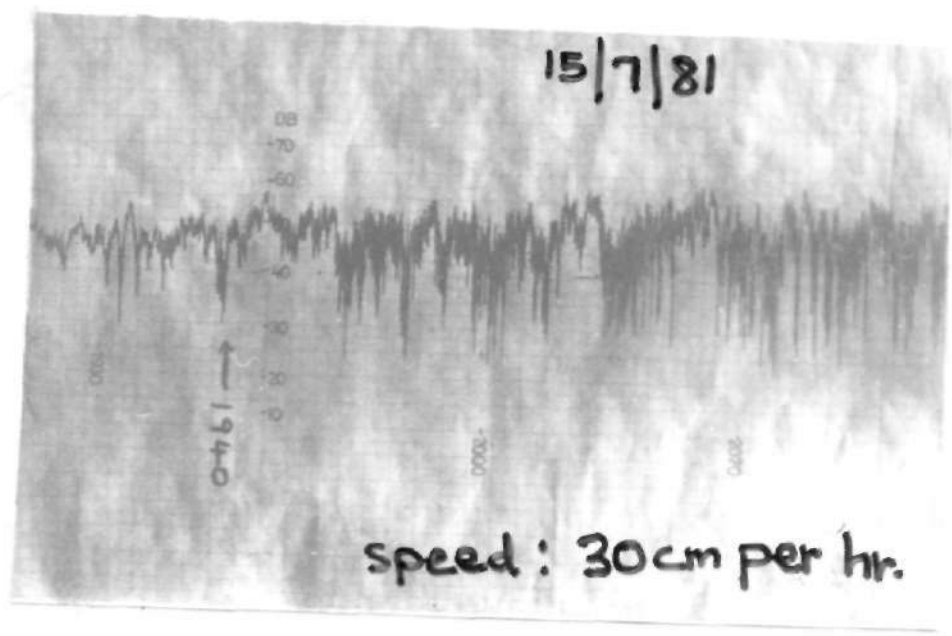


(b) Night-time recording

Fig.3.4: Daytime and night-time recordings for 593 kHz transmitter (FRCN, Kaduna). The transmitting antenna is 38 km from the research hut in Samaru, Zaria.

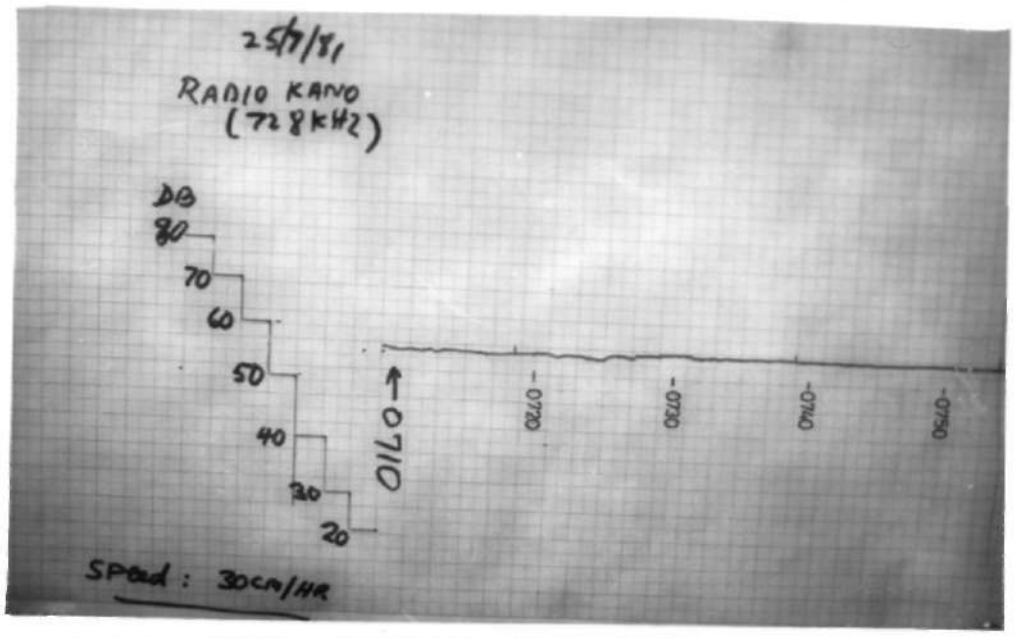


(a) Daytime recording

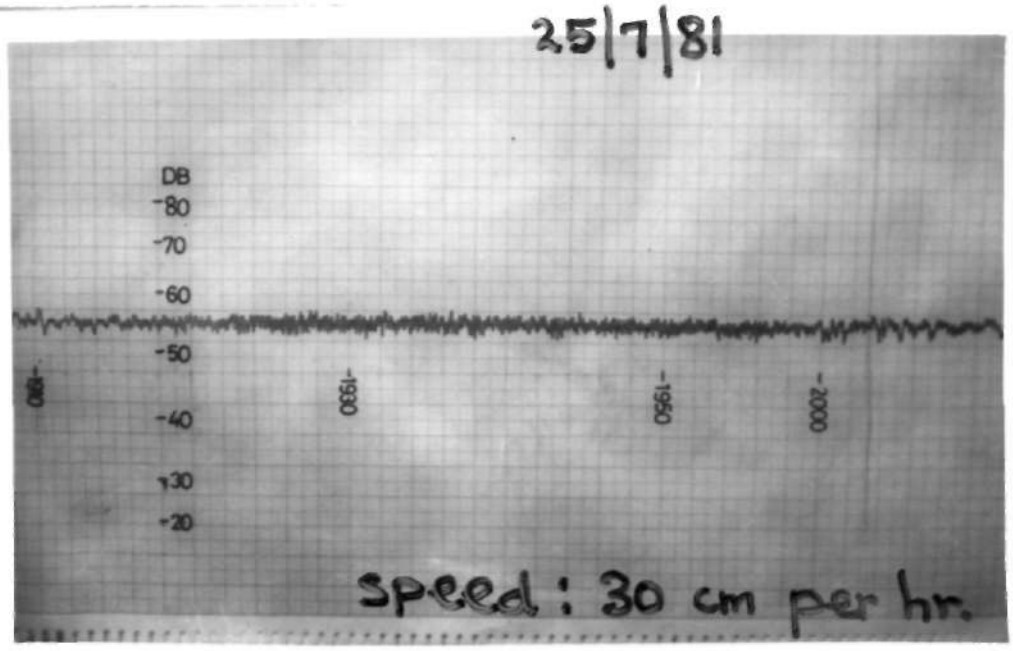


(b) Night-time recording

Fig. 3.5: Daytime and night-time recordings for 557 kHz transmitter (Rima Radio, Sokoto). The transmitting antenna is 322 km from the research hut in Samaru, Zaria.



(a) Daytime recording



(b) Night-time recording

Fig. 3.6: Daytime and night-time recordings for 728 kHz transmitter (Radio Kano). The transmitting antenna is 154 km from the research hut in Samaru, Zaria.

quarter wavelength. Daytime signal strength of medium wave, as a result, decreases more rapidly with distance the lower the earth's conductivity and the higher the signal frequency. Daytime attenuation in the D and E regions has been shown to be much greater than the night-time attenuation in the E region and must increase with decreasing wavelengths. At night when the D layer disappears sky wave signal reflected from the E layer may be received. Thus medium wave propagation takes place by both ground and sky waves at night-time. Both waves may arrive in phase or out of phase at the receiving antenna leading to constructive or destructive interference. From considerations of electron density of the ionosphere medium waves are thought to trace out a curved path as shown in figure 3.7.

Three cases of interference may be considered according to the distance from the transmitter. About the transmitter the ground-wave signal is stronger than the sky-wave signal even at night. As a result the received signal strength is practically independent of time of the day. This is illustrated in figure 3.4 with the 593 kHz transmitter (FRCN, Kaduna). The highest grade service is rendered in this region referred to as the primary service area. Primary coverage is dependent on the transmitter power, the directivity of the transmitting antenna, the earth's conductivity and the transmitted signal frequency.

At considerable distances from the transmitter outside the primary coverage area the signal strength is decided during

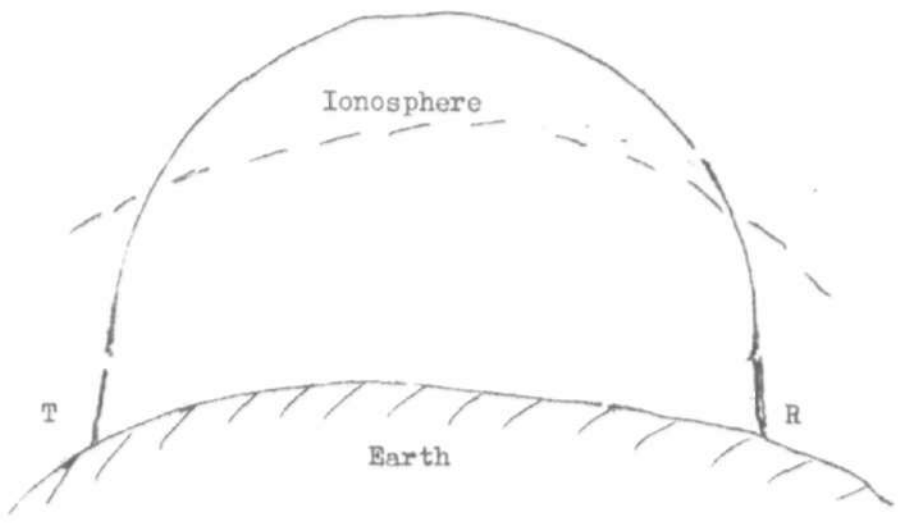


Fig. 3.7: Propagation of Medium Waves

the day by the ground waves and as a result the field strength is constant. But at night-time the sky wave signal is stronger than the ground wave resulting in fading. A lower grade of service is rendered in this region and this area is referred to as the secondary coverage area. In this area the signal strength is often inadequate to override interference fully. Figure 3.5 illustrates reception in this area.

At large distances from the transmitter the ground wave signal is so weak that there is no reception during the day, but at night-time the sky wave signal is strong enough for good reception. The sky wave signal suffers a certain amount of fading and quality distortion due to time variations in the ionosphere.

3.7 The Influence of Storm on MW Reception[1,17,18]

Electrical noise is any undesired voltages or currents that ultimately appear in the load of communication receiver

(usually a speaker). This noise often appears as static and may be annoying, such as an occasional burst of static. If the noise is continuous and of large amplitude the desired information may be suppressed.

Atmospheric radio noise is caused by storm in the earth's atmosphere. Radiation fields of lightning discharges contribute more to atmospheric noise. The frequency spectrum of atmospheric noise spreads over the entire radio spectrum, but its intensity is inveresely related to frequency. Hence, it is most troublesome at the lower frequencies. It is heard as static noise on standard AM radio receiver and is less troublesome for frequencies exceeding 20 MHz. If the noise is from local or near storms it gives rise to "crackles" and "bangs" repeating at regular intervals of time. But, if the noise is from distant storm it gives a continuous background of noise in the receiver.

If atmospheric noise exists in the vicinity of transmitted radio signal and contains some similar frequencies these two signals will "add" together. This is quite an undesirable phenomenon. The intensity of interference to radio reception is dependent on the type of discharge and power radiated by a flash. We can have discharge within the cloud or discharge from cloud to ground which can affect MW band reception.

3.8 Hourly Variations of Measured Field Strength

The hourly medians of the relative field strength are presented in table 3.1. The field strength is plotted against

local time as shown in figure 3.1. The duration of recordings was from 0700 - 2200 hrs.

The conclusions are as follows:

1. For the 593 kHz transmitter (FRCN, Kaduna) the difference between the minimum (75.5 dB) and maximum (77.2 dB) values recorded for the months, April - July from 0800 - 1800 hrs was 1.7 dB. Thus, the field strength could be said to be essentially constant in that duration. The recordings for this station are indicated in figure 3.4.

2. Generally, from 0800 - 1800 hrs the field strength was constant for the 557 kHz transmitter (Rima Radio, Sokoto); the difference between maximum (44.2 dB) and minimum (42.0 dB) values of the field strength being 2.2 dB. Outside the duration 0800 - 1800 hrs the field strength reached as high as 52.3 dB and as low as 41.6 dB during fading. Highest values were recorded towards 2200 hrs. Recordings for this station are shown in figure 3.5.

3. For the 728 kHz transmitter (Radio Kano) the lowest values were recorded in July and the difference between minimum (55.0 dB) and maximum field strength (58.1 dB) was 3.1 dB from 0800 - 1800 hrs. An extraordinary reason for the low values recorded in July may be due to the lowering of the transmitter power or low voltage supply from N.E.P.A. However, April, May and June recordings were fairly constant since the difference between the minimum (56.3 dB) and

and maximum (58.1 dB) values was 1.8 dB from 0800 - 1800 hrs. Recordings for this station are indicated in figure 3.6.

4. Little could be said about the 702 kHz transmitter (Radio Niger, Minna) recordings since the field strength variations were random. The transmitting antenna is about 208 km from the research hut. The field strength reached as high as 44.6 dB in the night-time and as low as 34.5 dB around 0700 hrs. The reason for the random variations of the signal strength may be due to the constant bad weather (rain storm and the associated thunderstorm) around the transmitter location as the reception from this station was most of the time noisy.

3.9 Daily Variations of Measured Field Strength

The daily medians of the field strength are indicated in table 3.2 and the corresponding graph is shown in figure 3.2.

The conclusions are as follows:

1. The difference between the minimum (75.5 dB) and maximum (77.4 dB) of the signal strength for the 593 kHz transmitter was 1.9 dB. The field strength radiated from this station may thus, be said to be constant from April - July.

2. The signal strength was fairly constant for the transmission from the 557 kHz transmitter since the maximum (43.8 dB) and minimum (41.5 dB) values differed by 2.3 dB.

3. For the 728 kHz transmitter 2.5 dB was the difference between the maximum (58.1 dB) and minimum field strength

(55.6 dB). Thus, the field strength transmitted from this station remained fairly constant.

4. The minimum (39.1 dB) and maximum field strength (41.8 dB) for the 702 kHz transmitter differed by 2.7 dB which could be associated with constant signal strength transmission from this station.

3.10 Monthly Variations of Measured Field Strength

The monthly medians of the signal strength and the corresponding graph are indicated respectively in table 3.3 and figure 3.3.

The conclusions drawn are as follows:

1. The signal strength radiated from the 593 kHz transmitter was constant since the highest (77.0 dB) and least (75.9 dB) values differed by 1.1 dB.

2. Radiation from the 557 kHz transmitter was equally constant as the least (42.4 dB) and highest signal strength (43.2 dB) differed by 0.8 dB only.

3. A constant signal strength was recorded for the 728 kHz transmitter since the highest (57.6 dB) and least (55.7 dB) values differed by 1.9 dB.

4. The least (39.0 dB) and highest signal strength (40.8 dB) radiated from the 702 kHz transmitter differed by 1.8 dB which was essentially a constant radiation.

3.11 General Interpretation

By careful examination of tables 3.1 and 3.2 it is seen that the signal strength may be slightly higher in the dry season than in the rainy season at one instant and at another instant it is the reverse for the same station. Since it is known that the ground conductivity increases in its value as the moisture content increases it may be concluded that the increase in the value of the ground conductivity in the rainy season has influenced the signal strength very little that it is not noticed.

In general, the difference between maximum and minimum signal strength recorded was around 2 dB in the daytime, with the accuracy of indication of the meter used in the recordings (in the linear range) with rod antenna being less than $\pm$ 2 dB. Thus, it is possible that the accuracy provided by the meter did not allow the minute variation of the signal strength as a result of the variation of the ground conductivity to be detected.

From another consideration surface objects like vegetation, hills and buildings attenuate ground waves, especially in the rainy season when trees have more leaves. Thus, while surface objects attenuate ground waves on one hand the ground conductivity which increases with moisture content in the rainy season increases ground-wave field strength on the other hand.

Ths situation is, thus, one of constant field strength depending on the relative influence of the surface objects

and the variation of the ground conductivity. As a result, the effective ground conductivity is constant. However, it should be noted that these studies are preliminary and, therefore, not conclusive as they do not cover one year of recording. They only show that there is need for further work in this investigation.

CHAPTER FOUR

THE DETERMINATION OF GROUND CONDUCTIVITY IN THE NORTHERN PARTS OF NIGERIA

4.1 Introduction

Efforts were made in the past to estimate the ground conductivity in Nigeria. The International Telecommunications Union proposed that a majority of the northern parts of Nigeria has a ground conductivity of 3 mmho/m.[19,20] Ajayi and Owolabi[4] contributed by plotting theoretical ground-wave propagation curves which could be used to estimate ground conductivity in Nigeria. They even carried out some determinations of ground conductivity. Two final year students, Badmos[11] and Pindar[12] had, as part of their project, undertaken measurements of ground-wave field strength along certain directions in the northern parts of Nigeria. These efforts are considered to be preliminary to the ultimate emergence of ground conductivity and field strength maps for the whole of Nigeria.

In this work the ground conductivity was estimated by the ground-wave attenuation and resistivity methods.

4.2 Measurements of Ground-Wave Attenuation

The technique in the measurement of ground conductivity by the ground-wave attenuation method lies in making measurements of the attenuation with distance of waves transmitted along the ground in the service area of a given radio station. By the comparison of the normalized field

strength plotted against distance from the transmitting antenna with the theoretical propagation curves plotted for the transmission frequency of the radio station the ground conductivity may be deduced. Propagation curves have been plotted for several stations and presented in appendix 3. These curves may be utilized for ground conductivity deductions.

In this research measurements of the ground-wave field strength were taken in the daytime when the field strength radiated from the MW radio stations should be fairly constant. The MW radio stations whose radiations were measured were:

Rima Radio, Sokoto (557 kHz)[1],
FRCN, Kaduna (593 kHz),
Radio Niger, Minna (702 kHz),
Radio Kano, Kano (728 kHz)[1].

The measurements were taken with the Potomac Instruments Inc. field strength meter, FIM - 21 whose block diagram is indicated in figure 4.1. The field strengths were measured in various directions as follows:

(1) Samaru/Kano road junction - Hunkuyi - Makarfi - Kura - Kano.

(2) Kaduna - Sabon Birnin Gwari - Tegina.

(3) Kaduna - Abuja - Izom - Minna.

(4) Kaduna Railway Station - Minna Railway Station (by train).

(5) Kaduna - Kujama - Kufana - Kachia - Kafanchan - Mariri - Saminaka - Pambeguwa - Katabu

(6) Samaru (Zaria) - Shika - Funtua - Malumfashi - Katsina - Batagarawa - Dutsinma - Kankara.

(7) Shika - Funtua - Mairuwa - Chafe - Denge - Sokoto.

The measured field strengths in dB referred to 1 micro-volt/m are presented in appendix 4.1 for the various directions. The locations where the measurements were taken and the corresponding distances from the transmitting antennae are indicated as well as the dates of the measurements. The map of the North-Central State of Nigeria of scale 1: 500,000 published by the North-Central State Surveys and printed in 1972 by the Survey Unit of the Kaduna Polytechnic and the administrative map of Nigeria of scale 1 : 1,000,000 printed in 1924 were used in determining the distance of the locations from the transmitting antennae.

4.3 Short Description of Equipment

The Potomac Instruments Inc. field strength meter, FIM - 21 which was used in taking the measurements is a rugged light-weight portable equipment for the measurements of radio signal intensities in the broadcast band 540 - 1600 kHz. It is capable of measuring field intensity range, 10 microvolts per meter to 10 volts per meter. The calibration accuracy is 1 percent, reference to NBS standard

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[1] Refer to page 24 for the current transmission frequencies.

field, and the range - attenuator accuracy is 2 percent over the entire FI range and tuning band.

The functional block diagram is shown in fig. 4.1. It is made up of seven major sections:

1. A loop antenna
2. A very stable AM superheterodyne receiver
3. A 20 dB per step RF/IF attenuator within the receiver
4. A calibration oscillator
5. A gain comparison (null) circuit
6. A penel meter
7. A regulated power supply

A full description of the operations of the sections has been described in the manual.(21)

A shielded unbalanced loop antenna is used to reduce electric pick-up and is thus free from hand capacity effects. Again, this sort of antenna is used because of its directivity characteristics. The signal from the antenna is fed into the receiver. Tuning is facilitated by using the panel speaker, the panel meter, or the headphones.

The RF attenuator is switched by the FULL SCALE switch in three 20 dB steps to provide part of the measurement range. Measurements of signals over a range of 10 microvolts to 10 volts are possible. The RF attenuator output is fed to a broadband RF amplifier and mixer. The local oscillator

is tunable over the entire RF range to produce an IF frequency of 455 kHz.

A ceramic filter and RF tuned circuits decide the receiver selectivity. The IF output is fed to a resistive IF attenuator and then to IF amplifier. The IF gain is controlled by a front panel control, and in the LOG mode, by a voltage fed back from the detector. The receiver detector supplies voltages to the meter, the audio circuit, the calibrating circuit, and to a simple d.c. amplifier that provides the RECORDER output.

For absolute measurements of signal intensity in volts per meter the calibration oscillator is included. A full detail of the calibration procedure is in the manual.(21) Briefly, in the calibration process the gain of the receiver is set at the frequency of transmission of a radio station. A reference signal is provided in the receiver by the calibration oscillator for this purpose. During the calibration we aim at equalising the output voltages of the receiver detector and the calibration oscillator detector. The null circuit is used to compare the two outputs and it produces meter reading that is minimum when the voltages are equal. The calibration oscillator also provides a reference level for the null circuit. When the calibration is completed the calibration is correct across the full frequency range, 540 to 1600 kHz.

D.C. power supply is obtained from series-connected six 1.5-volt cells and a simple voltage regulator having an output of - 6.0 volts.

4.4 Normalization of Measured Field Strength

The measured field strength has to be normalized to the effective radiated power of 1 kW before the propagation curves shown in appendix 3 may be used to estimate the ground conductivity. The measured field strength can be normalized to an e.r.p. of 1 kW by means of the following expression,

$$F_N = F_M - 20 \log_{10} \sqrt{P}$$

or,

$$F_N = F_M - 10 \log_{10} P \quad \ldots\ldots (4.1)$$

where F_M is the measured field strength in dB,

P is the effective transmitter power in kW, and

F_N is the normalized field strength.

Example:

The 593 kHz transmitter (FRCN, Kaduna) provides a ground wave having a strength of 60.0 dB at a distance of 98 km. If the effective transmitter power is 10 kW, compute the normalised field strength.

Solution:

Using eqn 4.1 the normalized field strength,

$$F_N = 60 - 10 \log_{10} 10$$

$$= 60 - 10 \text{ dB}$$

$$= 50 \text{ dB}$$

The normalized field strengths are also indicated in appendix 4.1 which were utilized in the ground-conductivity estimations.

4.5 Development of Computer Technique for Plotting Normalized Field Strength

The normalized field strength was plotted against distance from the transmitter on the propagation curves prepared for the four MW radio stations. Measurements of field strength for distances exceeding 200 km were not plotted because the curves were prepared for distances from 5 km to 200 km. It is so because the maximum distance from the transmitting antenna at which the earth's curvature is entirely negligible is given by,

$$D_{max} = 80/f^{\frac{1}{3}} \text{ (km)} \quad .... \quad (4.2)$$

where f is the transmission frequency in MHz. D_{max} has been computed for the radio stations and indicated in table 4.1. The theoretical propagation curves may still be used in estimating the ground conductivity for distances exceeding D_{max}

since no serious error arises until the distance from the transmitter exceeds $2D_{max}$ [7], (refer to table 2.2).

TABLE 4.1

TRANSMISSION FREQUENCIES (f) (MHz)	. 557	. 593	. 702	. 728	. 729
D_{max} (km)	97.2	95.2	90.0	88.9	88.9

A CALCOMP Plot FORTRAN IV programme was developed for plotting the theoretical propagation curves, as discussed in section 2.5, and for plotting the normalized field strength on the propagation curves successively. The computer programme is indicated in appendix 4.2 for the measurements taken along the direction, Samaru/Kano road junction - Hunkuyi - Kura - Kano for the 593 kHz transmitter. A manual was established in this work on the CALCOMP programme. It is merely an extension of that shown in appendix 1 for plotting only the propagation curves. The CALCOMP plots were also done on the digital computer, model CY 72 manufactured by Control Data Corporation, U.S.A. installed at A.B.U. Computer Centre, Zaria. The plots are presented in figs. 4.2 to 4.7 for the various directions.

4.6 Deductions of Ground Conductivity

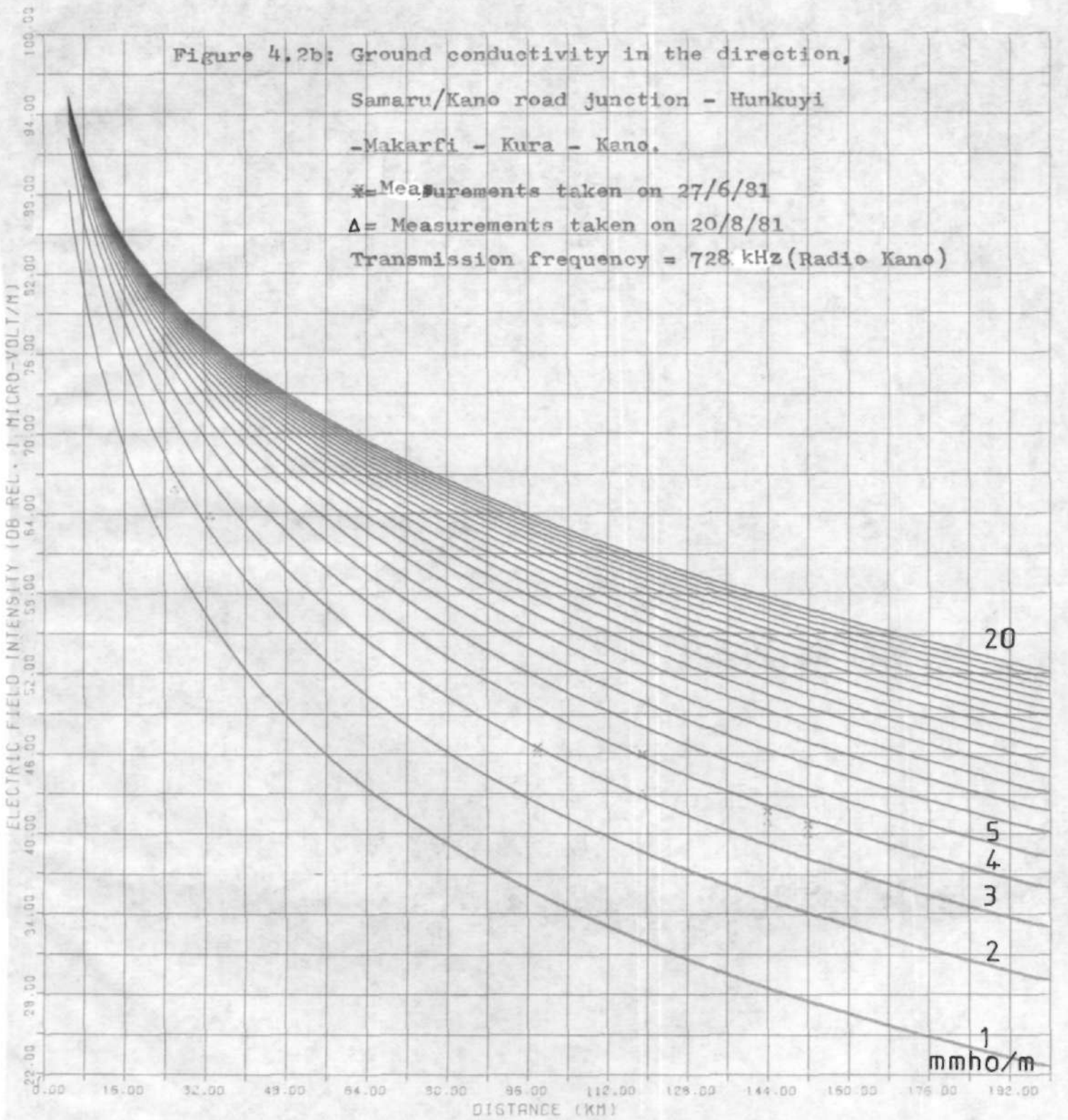
The average ground conductivity in the various directions were deduced from figs. 4.2 to 4.7. The deductions in the

Figure 4.2b: Ground conductivity in the direction, Samaru/Kano road junction - Hunkuyi -Makarfi - Kura - Kano.

x= Measurements taken on 27/6/81

Δ= Measurements taken on 20/8/81

Transmission frequency = 728 kHz (Radio Kano)



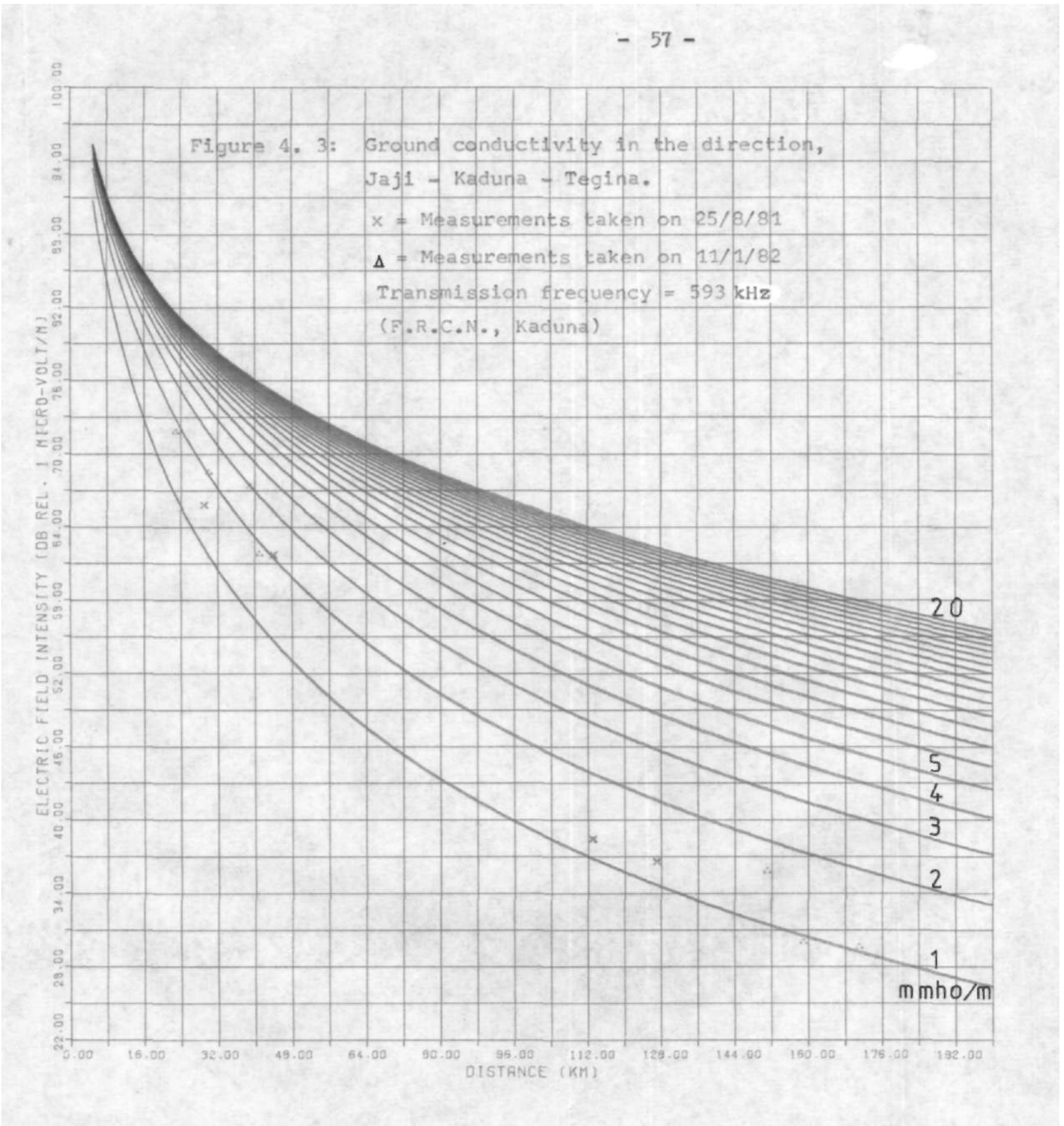


Figure 4. 3: Ground conductivity in the direction, Jaji - Kaduna - Tegina.

x = Measurements taken on 25/8/81

Δ = Measurements taken on 11/1/82

Transmission frequency = 593 kHz

(F.R.C.N., Kaduna)

Figure 4. 4a: Ground conductivity in the directions, Kaduna - Abuja - Minna (by road), and Kaduna - Minna (by train)
x = Measurements taken on 20/6/81 (by road)
Δ = Measurements taken on 15/8/81 (by train)
Transmission frequency = 593 kHz
(F.R.C.N., Kaduna)

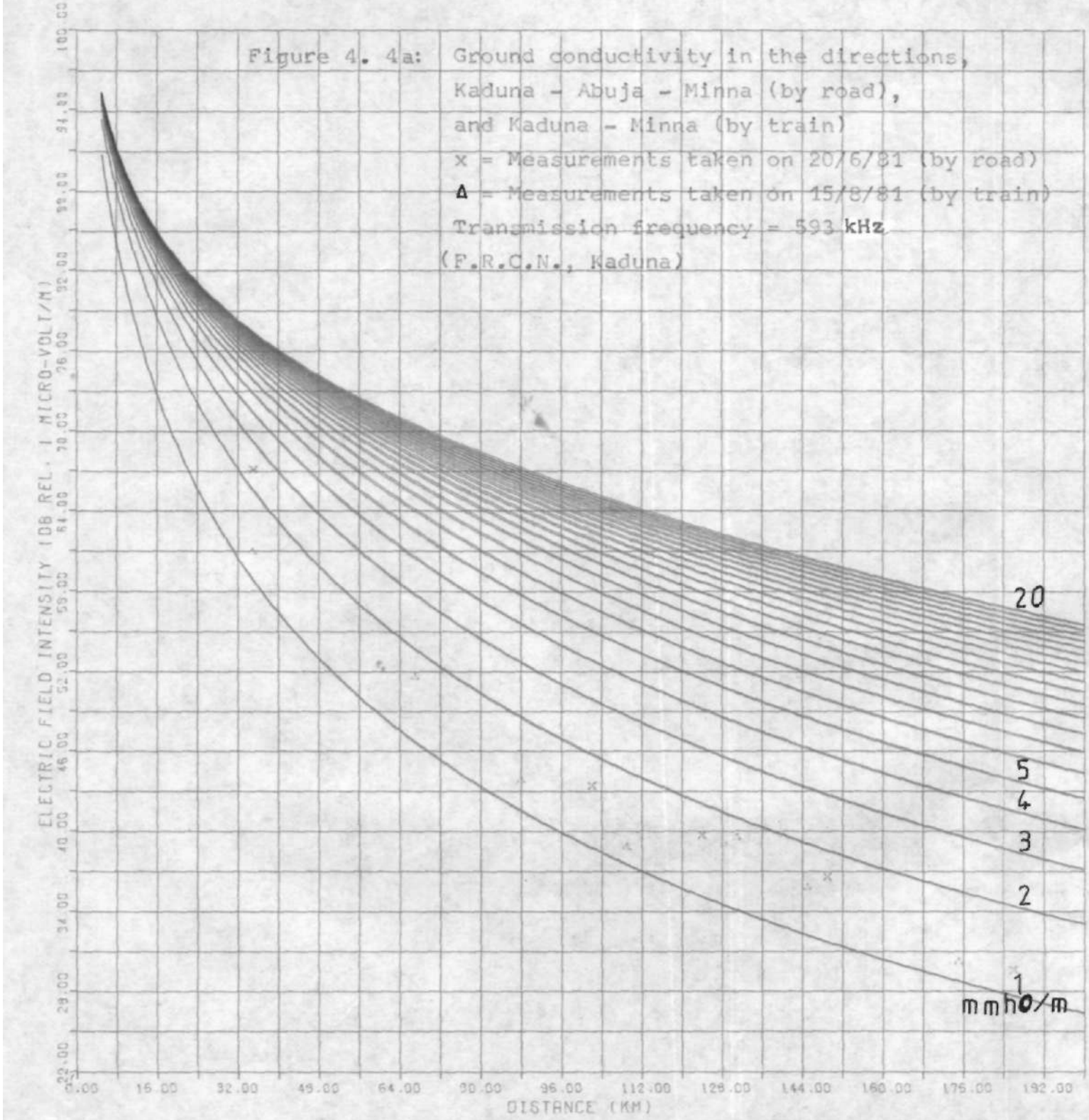


Figure 4. 4b: Ground conductivity in the directions, Kaduna - Abuja - Minna (by road), and Kaduna - Minna (by train)
x = Measurements taken on 20/6/81 (by road)
Δ = Measurements taken on 15/8/81 (by train)
Transmission frequency = 702 kHz (Radio Niger).

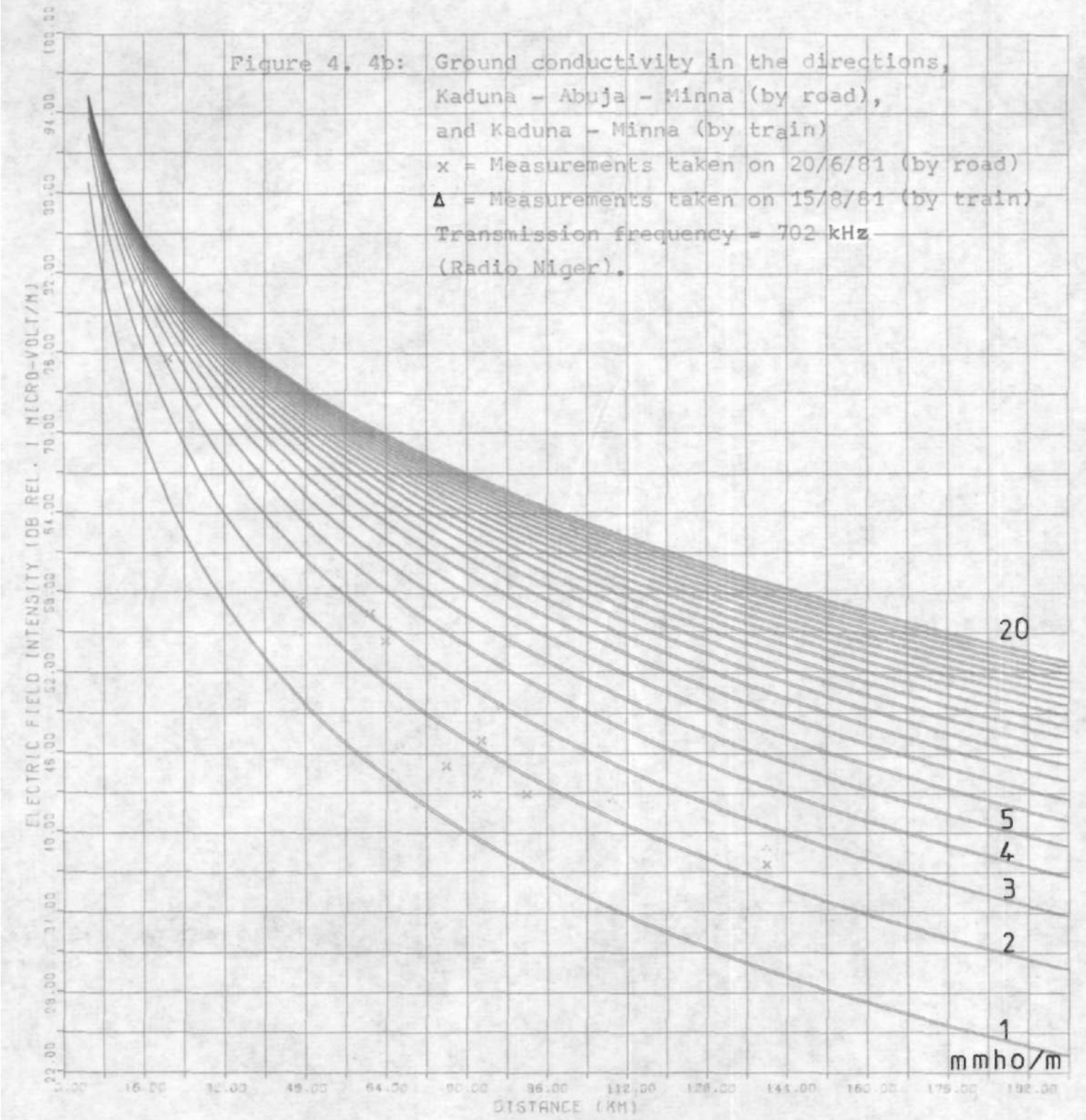


FIGURE 4.5: GROUND CONDUCTIVITY IN THE DIRECTION, KADUNA-KUFANA - KAFANCHAN - KATABU
MEASUREMENTS TAKEN ON 22-23/8/81
TRANSMISSION FREQUENCY = 593kHz (F.R.C.N., KADUNA)

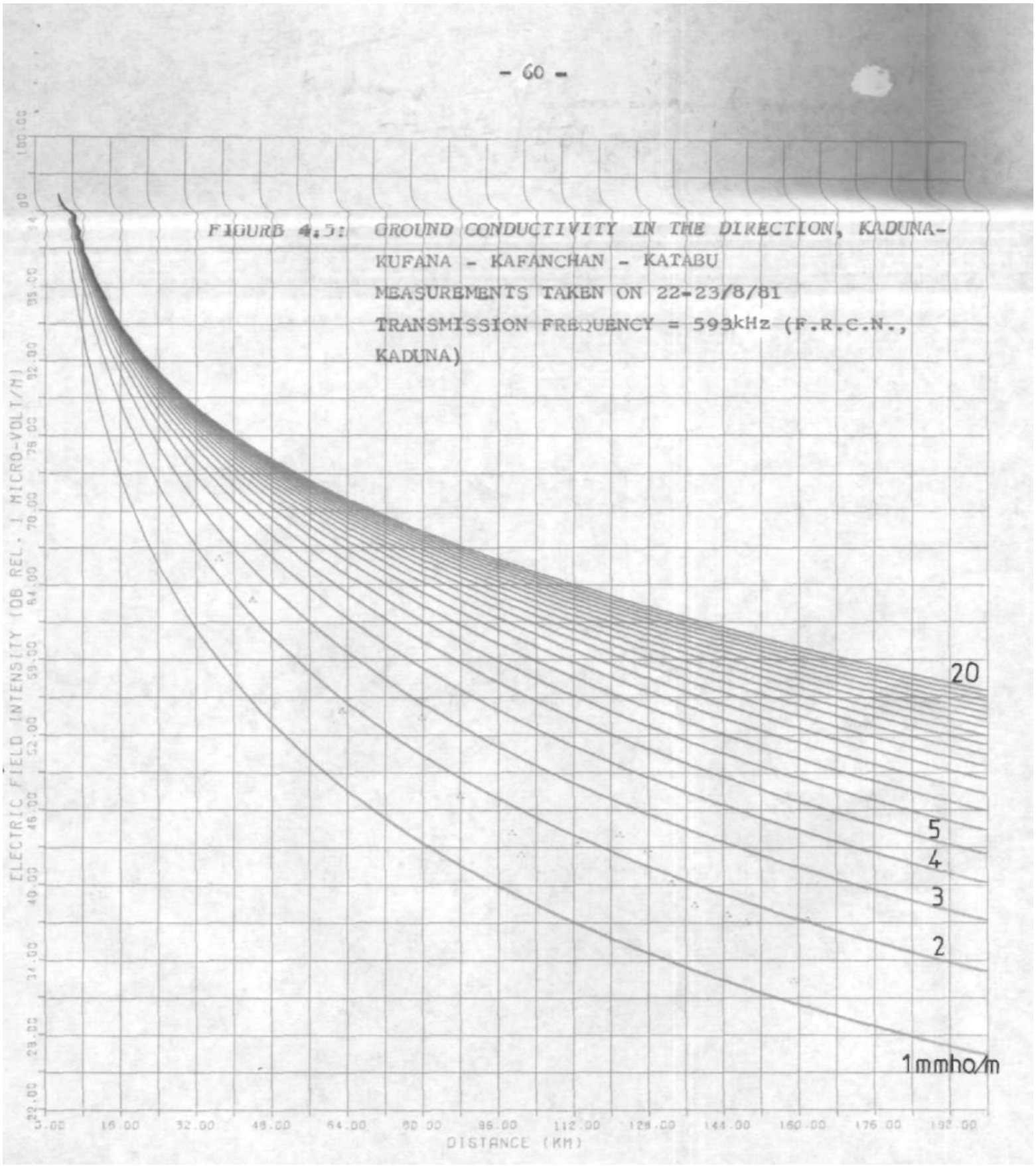


Figure 4. 6a: Ground conductivity in the direction, Samaru (Zaria) - Shika - Funtua - Malumfashi - Kankiya - Katsina - Dutsinma - Kankara
x = Measurements taken on 29/8/81
Δ = Measurements taken on 6/6/81
Transmission frequency = 593 kHz
(F.R.C.N., Kaduna)

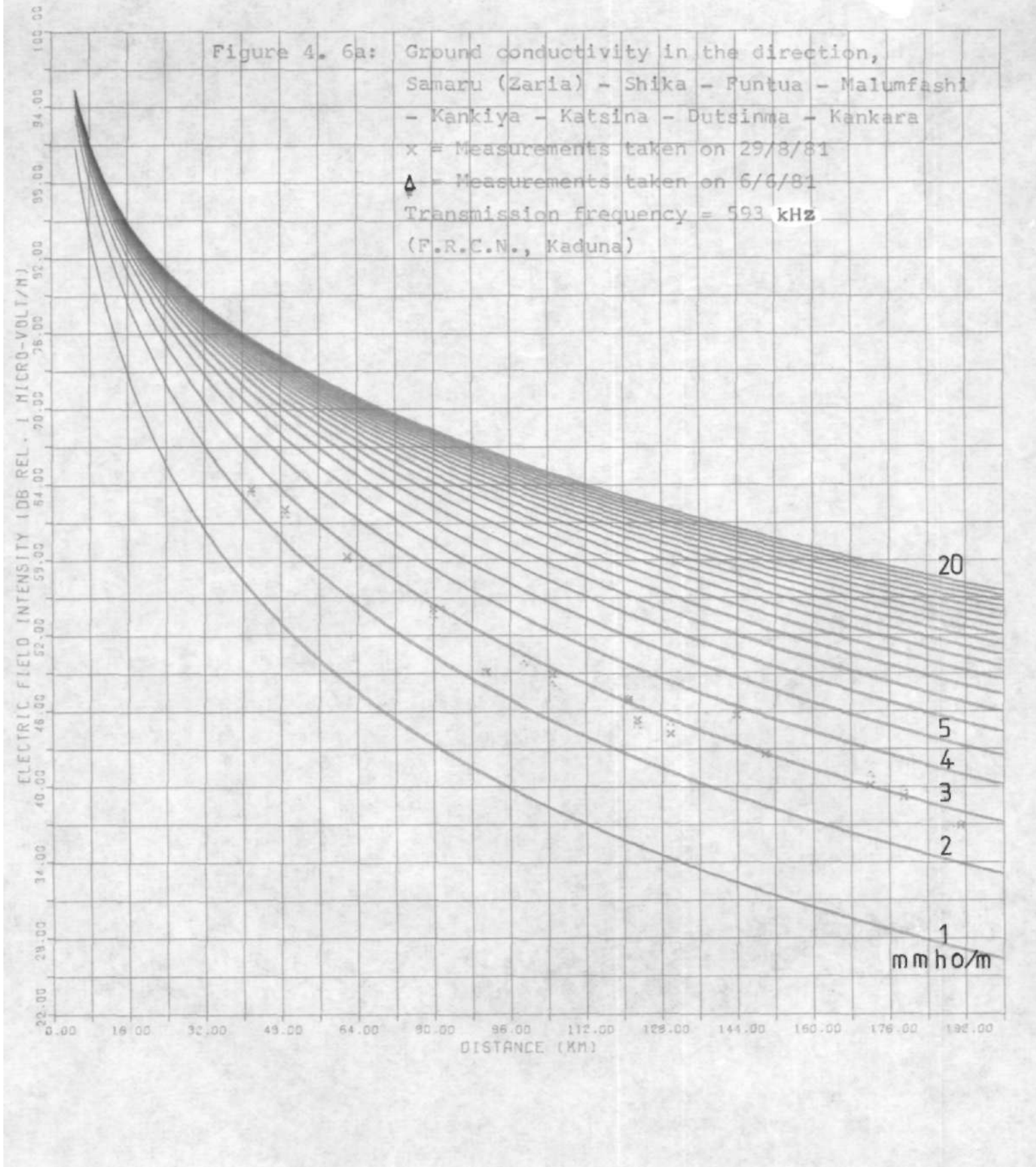


Figure 4. 6a: Ground conductivity in the direction, Samaru (Zaria) - Shika - Funtua - Malumfashi - Kankiya - Katsina - Dutsinma - Kankara
x = Measurements taken on 29/8/81
Δ = Measurements taken on 6/6/81
Transmission frequency = 593 kHz
(F.R.C.N., Kaduna)

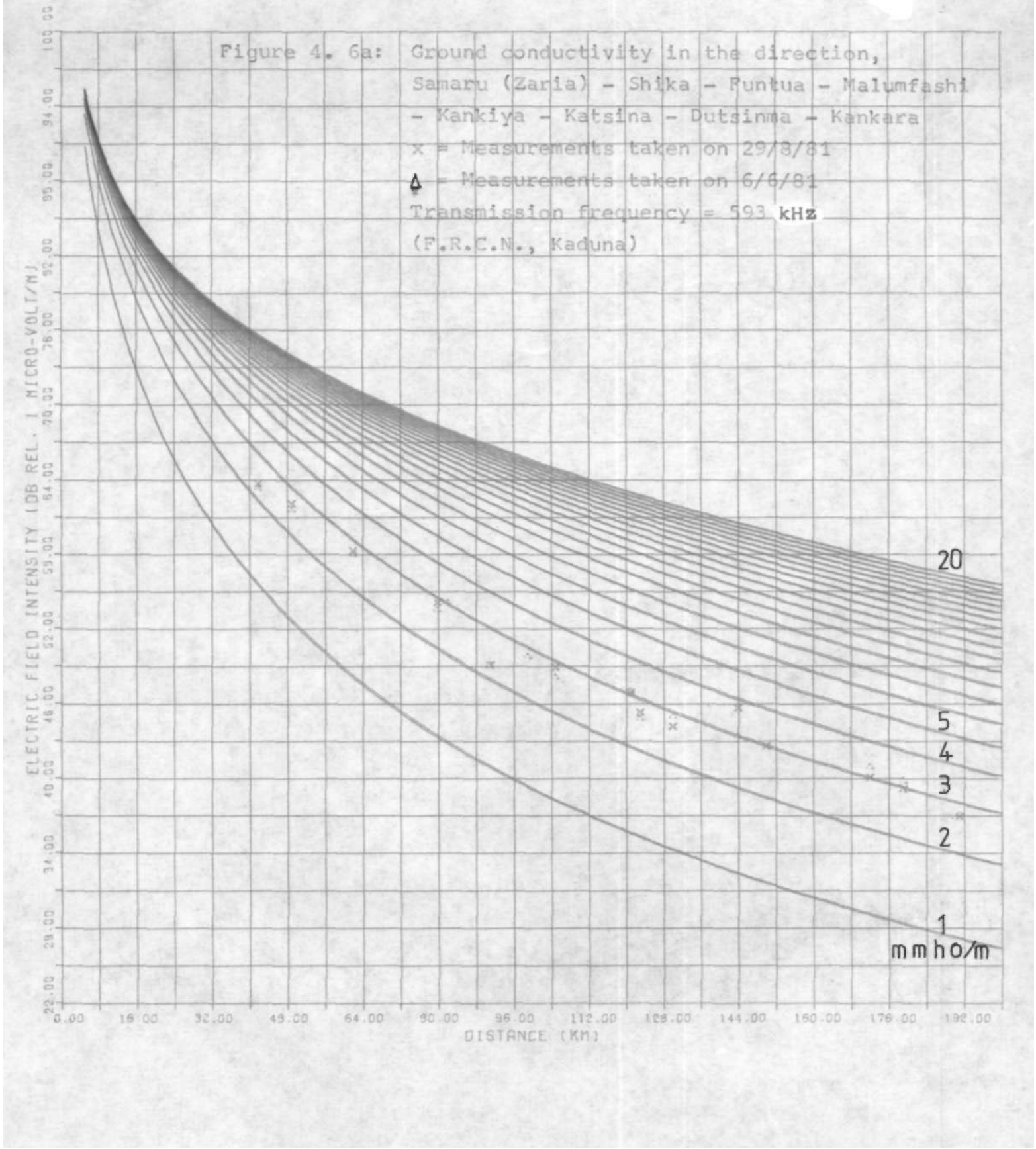


Figure 4. 6b: Ground conductivity in the direction, Samaru (Zaria) - Shika - Funtua - Malumfashi - Kankiya - Katsina - Dutsinma - Kankara
x = Measurements taken on 6/6/81
A = Measurements taken on 29/8/81
Transmission frequency = 720 kHz
(Radio Kano)

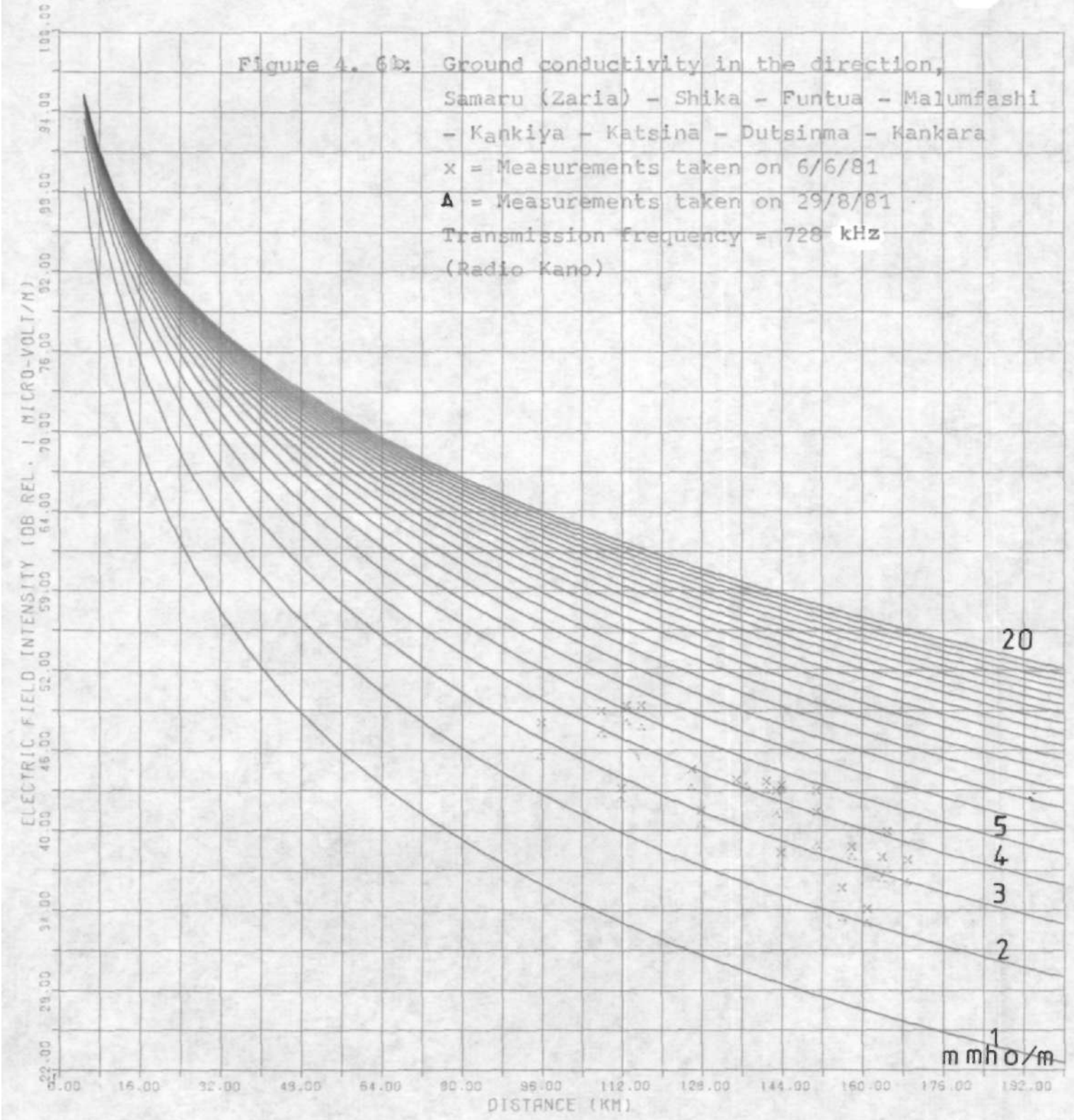


FIGURE 4.7a: GROUND CONDUCTIVITY IN THE DIRECTION, SHIKA - FUNTUA - SOKOTO
X = MEASUREMENTS TAKEN ON 9/6/81
Δ = MEASUREMENTS TAKEN ON 9/1/82
TRANSMISSION FREQUENCY = 593 kHz
(F.R.C.N., KADUNA)

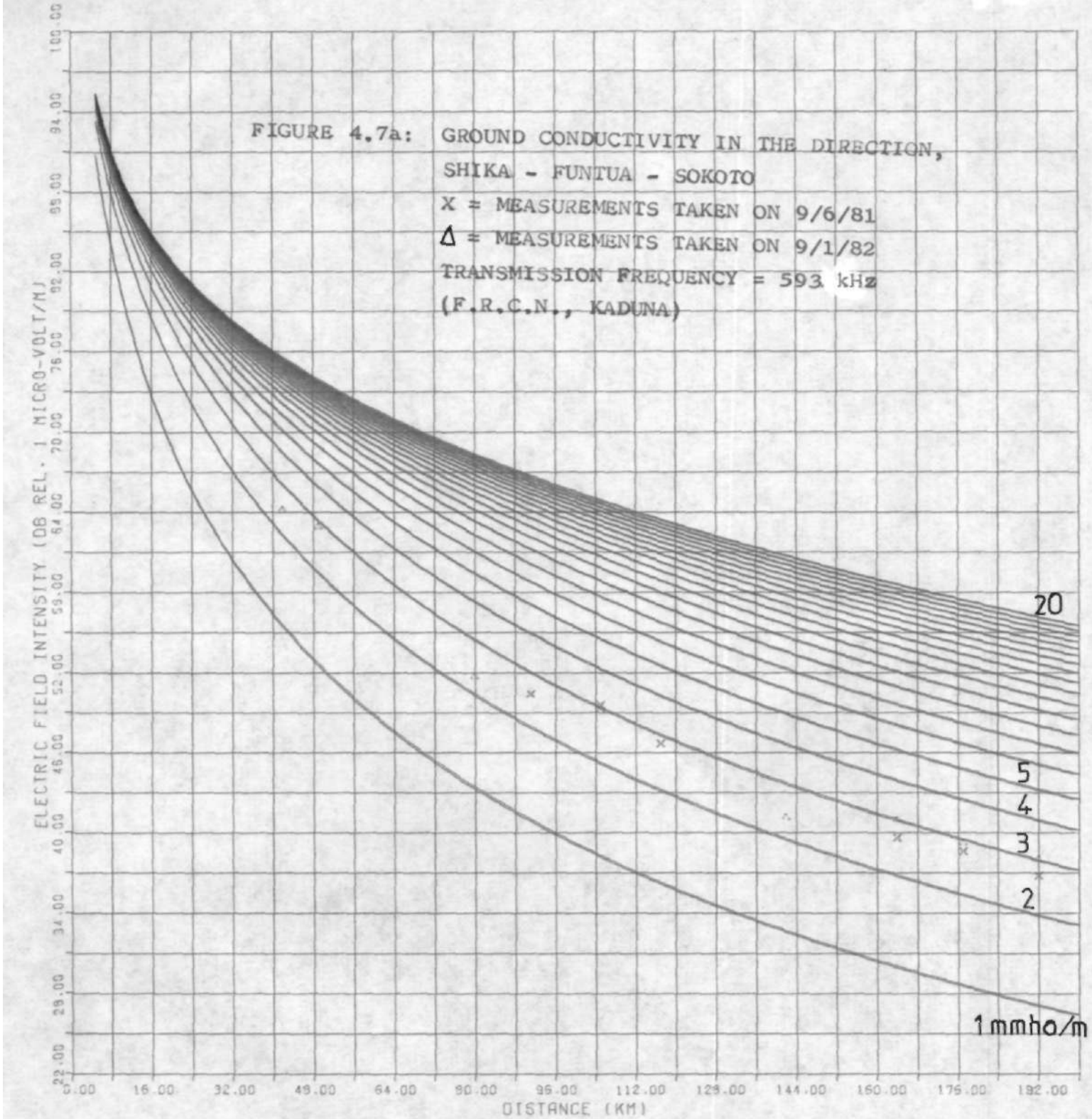


FIGURE 4.7b: GROUND CONDUCTIVITY IN THE DIRECTION, SHIKA - FUNTUA - SOKOTO
X = MEASUREMENTS TAKEN ON 9/6/81
Δ = MEASUREMENTS TAKEN ON 9/1/82
TRANSMISSION FREQUENCY = 557 kHz (RIMA RADIO, SOKOTO)

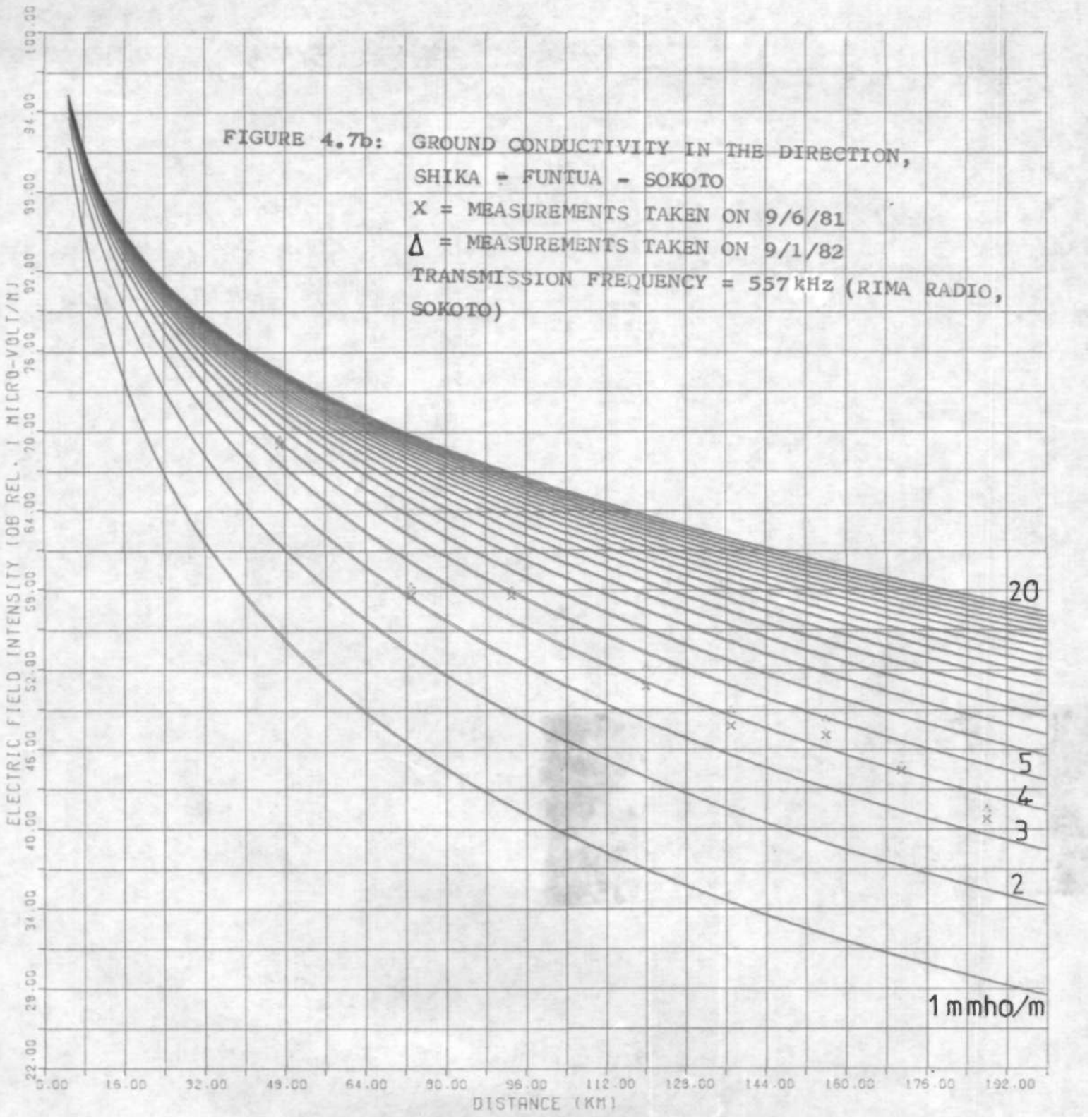
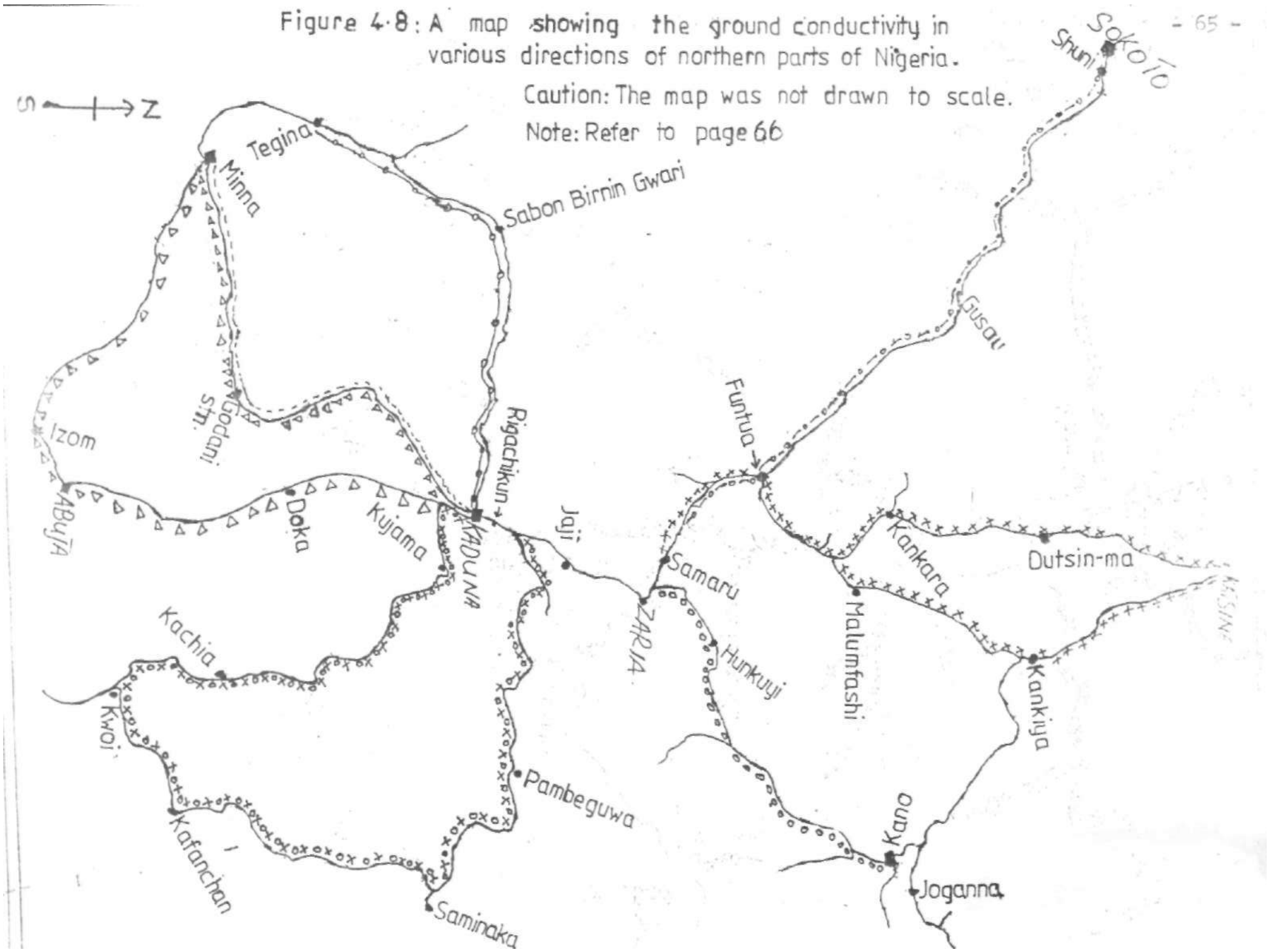


Figure 4·8: A map showing the ground conductivity in various directions of northern parts of Nigeria.

Caution: The map was not drawn to scale.

Note: Refer to page 66



Key for the various directions shown in figure 4.8 .

———	Road
— — —	Kaduna stn — Minna stn
—•—•—•—	Samaru — Sokoto → 9/6/81 & 9/1/82 { σ = 3 mmho/m for 593 kHz, and σ = 4 mmho/m for 557 kHz
× × × × ×	Samaru — Malumfashi — Katsina — Kankara → 6/6/81 & 29/8/81 { σ = 3 mmho/m for 593 kHz, and σ = 3 or 4 mmho/m for 728 kHz
° ° ° ° ° °	Samaru — Kano → 27/6/81 & 20/8/81 { σ = 3 mmho/m for both 593 and 728 kHz
×°×°×°×°×	Kaduna — Kafanchan → 22/8/81 & 23/8/81 { σ = 2 mmho/m for 593 kHz
——o——o——	Kaduna — Tegina → 25/8/81 & 11/1/82 { σ = 2 mmho/m for 593 kHz
△ △ △ △ △	Kaduna — Abuja — Minna and Kaduna stn — Minna stn → 20/6/81 & 15/8/81 { σ = 2 mmho/m for both 593 and 702 kHz

various directions were as follows:

1. Along Samaru/Kano road junction - Hunkuyi - Makarfi - Kura - Kano it was 3 mmho/m (fig. 4.2).

2. Along Kaduna - Sabon Birnin Gwari - Tegina it was 2 mmho/m (fig. 4.3)

3. (i) Along Kaduna - Abuja - Izom - Minna

   (ii) Along Kaduna railway station - Minna station (that is following the railway line).

   The average ground conductivity for both directions was 1.9 mmho/m using the 593 kHz transmitter; for the 702 kHz transmitter it was 2 mmho/m (fig. 4.4).

4. Along Kaduna - Kujama - Kufana - Kachia - Kafanchan - Mariri - Saminaka - Pambeguwa - Katabu the average value was 2 mmho/m (fig. 4.5).

5. Along Samaru (Zaria) - Shika - Funtua - Mairuwa - Malumfashi - Kankiya - Katsina - Batagarawa - Dutsinma - Kankara it was 3mmho/m. It was, however, 4 mmho/m for places like Jargaba road junction, Gora, Dayi, Musawa road junction, Dutsinma, Yan Tumaki and Kankara using 728 kHz (Radio Kano)(fig. 4.6). This result is discussed below.

6. Along Shika - Funtua - Mairuwa - Chafe - Denge - Sokoto it was 3 mmho/m for the 593 kHz transmitter from Shika - Bungudu and 4 mmho/m using 557 kHz (Rima Radio, Sototo) for the entire direction. Refer to figure 4.7. The discrepancy is explained in the next page.

The average ground conductivity in the various directions are shown on a map in fig. 4.8.

Discrepancies obtained using two transmitter frequencies for the same direction

It has been shown elsewhere[2] in figure 2 that for a given type of ground its conductivity is fairly constant over the MW band, 300 kHz - 3 MHz. Hence, measurement of the ground conductivity in a given direction may be expected to be fairly constant over the entire MW frequencies.

However, from figure 4.6 it is seen not to be so for the estimation along Samaru (Zaria) - Shika - Funtua - Mairuwa - Malumfashi - Kankiya - Katsina - Dutsinma - Kankara. Using the propagation curves for 593 kHz and 728 kHz showed that the average ground conductivities for this direction were respectively 3 mmho/m and 4 mmho/m. The striking thing about the plot for 728 kHz is that the plotted points are markedly scattered. This might be as a result of the variation of the effective radiated transmitter power or type of terrain. It is possible that there is (are) some other reason(s) for this scattering. There is the need to investigate this further. Radio Kano, whose latest transmission frequency is 729 kHz has two MW transmitters transmitting at this frequency. The effective radiated power of each transmitter was taken as 25 kW. The two transmitters can operate in parallel.

In the measurements for the direction, Samaru (Zaria) to Sokoto using the propagation curves for 593 kHz and 557 kHz the average ground conductivities were respectively estimated as 3 mmho/m and 4 mmho/m. The difference is attributed to the use of inaccurate effective radiated power in the normalization of the measured field strengths for the 557 kHz transmitter. Rima Radio, Sokoto, whose latest transmission frequency is 558 kHz has two MW transmitters transmitting at this frequency. The effective radiated power of each transmitter was taken as 25 kW. There is a possibility of parallel operation of the two MW transmitters.

4.7 Estimating the Ground Conductivity By the Ground Resistivity Method

The ground resistivity method of estimating the ground conductivity is carried out by passing a direct current between one pair of probes and measuring the resultant potential difference between the other pair of probes. In the measurements the Wenner configuration was adopted.[22,23,24] In this configuration the electrodes are arranged in a linear array ($C_1P_1P_2C_2$) as shown in figure 4.9.

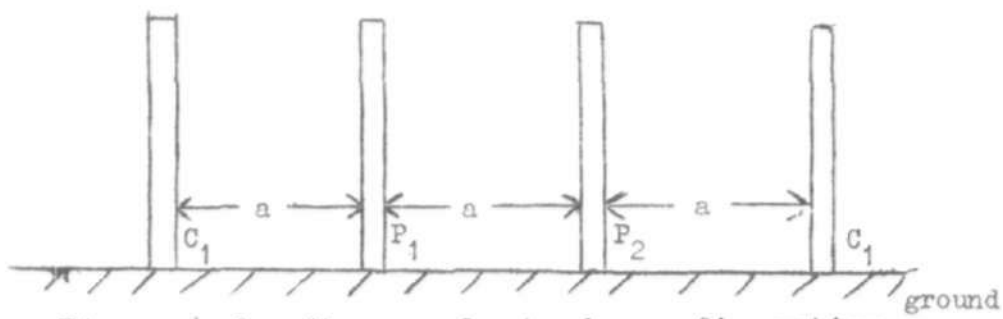


Figure 4.9: Wenner electrode configuration

The distances between the adjacent electrodes are equal (a) so that the apparent resistivity, ρ_a of the ground is given as

$$\rho_a = 2\pi a R \qquad \ldots\ldots \qquad (4.3)$$

where R = V/I which is of the nature of a resistance,

V is the p.d. between P_1 and P_2, and

I is the direct current flowing between C_1 and C_2,

ρ_a is called apparent resistivity if the ground at the measurement site is inhomogeneous. The reciprocal of ρ_a gives the ground conductivity at the measurement site. By virtue of Helmholtz's reciprocity theorem in the theory of electric circuits, the ratio V/I and hence ρ_a remain unchanged if the current and potential electrodes are interchanged. This is equally true for homogeneous and non-homogeneous ground.

Subsurface Exploration

The resistivity of the subsurface may be determined by two main ways:

1. electric sounding (or drilling)
2. electric mapping (or trenching)

Electric drilling with the Wenner configuration involves increasing the distance, a , in steps while the midpoint of the configuration is fixed. Because the fraction of the current penetrating to deeper levels increases with the

electrode separation, electric drilling furnishes information about the variation of electric conductivity with depth. However, the conductivity of the top part of the ground is just our interest in this research. Electric trenching with Wenner method involves moving an electrode array with a fixed, a , on the ground (normally along staked profiles) and the resistivity of each position is computed. Measurements obtained from electric trenching are influenced by lateral variations in the conductivity and are, therefore, most suitable for detecting variations in the ground conductivity along a given path.

Measurements and Instrumentation

To measure the resistance between two electrodes placed on the surface of the ground a problem arises due to the fact that most of the resistance is located near the electrodes. Also the sizes or shapes of the electrodes greatly influence the results obtained. Four electrodes are, therefore, normally used. In figure 4.10, P_1 and P_2 are the potential electrodes while C_1 and C_2 are the current electrodes.

In the measurements copper stakes were used as the electrodes. The current (I) was measured with a sensitive multimeter and the p.d. (V) was measured with a battery operated digital multimeter. The power source was a 36 ampere/hour 12 V accumulator. The readings obtained with the arrangement shown in figure 4.10 are indicated in table 4.2.

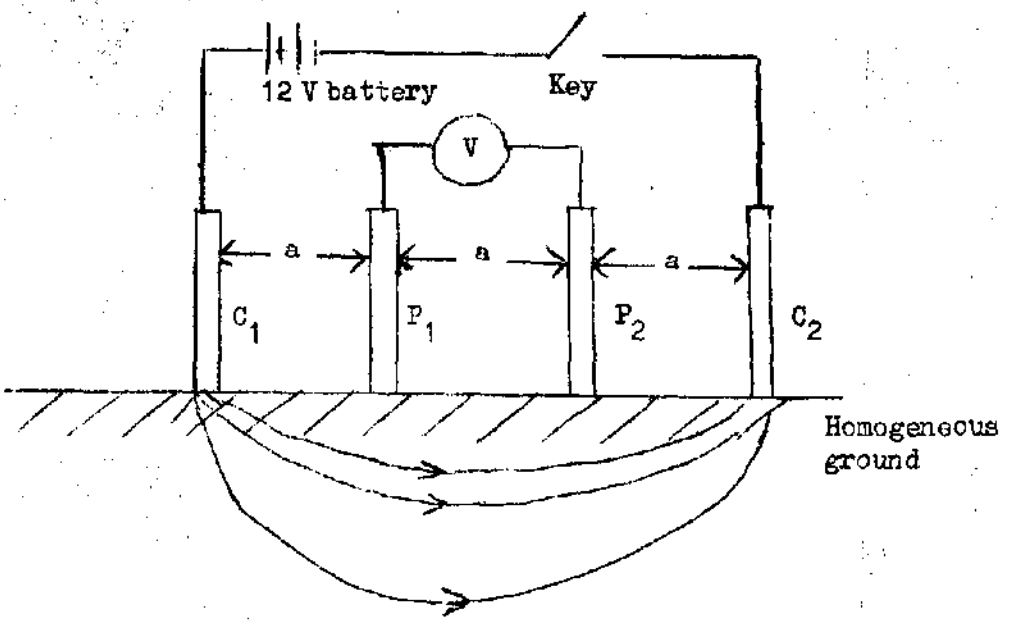


Figure 4.10: Experimental Set-up.

TABLE 4.2

Measurements around the Research Hut in Samaru

Date	I/mA	p.d./V	Separation, a/cm
6/4/81 1	.025	.078	5
2	.400	.132	10
3	.093	.040	15
16/4/81 1	.095	.172	5
2	.165	.140	10
3	.070	.023	15
4	.075	.042	20

Solving for electric conductivity

Apply $\rho = 2\pi a R$, and $R = V/I$

6/4/81

(1) $\rho = 2 \times \frac{5}{100} \times \frac{0.078}{.025 \times 10^{-3}}$

$= .98 \times 10^3$ ohm-m

$\therefore$ the ground conductivity = 1 mmho/m

(2) Similarly, $\rho = .21 \times 10^3$ ohm-m

$\therefore$ the ground conductivity = 4.82 mmho/m

(3) $\rho = 2.19 \times 10^3$ ohm-m

$\therefore$ the ground conductivity = 0.50 mmho/m

The average ground conductivity $= \frac{1 + 4.82 + 0.5}{3}$

$= 2.1$ mmho/m

16/4/81

(1) $\rho = 2\pi \times \frac{5}{100} \times \frac{.172}{.095}$

$= .5688 \times 10^3$ ohm-m

$\therefore$ the ground conductivity = 1.8 mmho/m

(2) Similarly, $\rho = .5331 \times 10^3$ ohm-m

$\therefore$ the ground conductivity = 1.9 mmho/m

(3) ρ = .3097 x 10^3 ohm-m

$\therefore$ the ground conductivity = 3.2 mmho/m

(4) ρ = .7037 x 10^3 ohm-m

$\therefore$ the ground conductivity = 1.4 mmho/m

The average ground conductivity =

$$= \frac{1.8 + 1.9 + 3.2 + 1.4}{4}$$

= 2.1 mmho/m

Comments on the results

With small electrode spacing (as is the case in table 4.2) the associated resistivity is called the surface resistivity. A power source of several volts, d.c. or low frequency a.c. (less than 60 Hz) is required for larger spacing of the electrodes.

2.1 mmho/m was obtained as the ground conductivity around the research hut in Samaru. This result might have been influenced by electrolytic polarization and self potential (SP) and thus,

1. To counteract the effects of electrolytic polarization due to unidirectional current the d.c. polarity should be periodically reversed by using, for instance, a reversing switch.

2. Using a d.c. power source requires the determination of the self potential before the power source is turned on which is then subtracted from the potential measured when current is flowing.

Self potentials arise as a result of electric currents in the ground. They are d.c. potentials set up due to electro-chemical actions in the surface rocks or in bodies buried in them. The use of a.c. or rapidly interrupted d.c. counteracts the SP effect.

4.8 General Comments on the Ground Conductivity Deductions

The International Telecommunications Union (ITU)[19,20] classifies electric conductivity as shown in table 4.3. If the majority of the Northern States of Nigeria is accepted to have a ground conductivity of 3 mmho/m as proposed by ITU then it means that the ground conductivity for the majority of the parts of Northern Nigeria lies between 1.8 and 5.5 mmho/m.

Earlier work by the personnel of the Radio Television, Kaduna[19] reveal that Kafanchan, Abuja and Jagindi towards the south might have a ground conductivity less than 3 mmho/m. According to the research results depicted in figure 4.8 Kafanchan and Abuja have a ground conductivity of about 2 mmho/m which supports the earlier proposal. Also, the values obtained in this work fall within 1.8 - 5.5 mmho/m which seems to confirm the proposal of ITU.

TABLE 4.3

Class of Conductivity in mmho/m	Conductivity ranges in mmho/m
1	0.55 - 1.8
3	1.8 - 5.5
10	5.5 - 18

CHAPTER FIVE

CONCLUSION

Theoretical ground-wave propagation curves were plotted for a number of broadcast frequencies being used in the Northern States of Nigeria. These curves could be useful in designing radio networks and were plotted on a digital computer. Temporal variations of ground-wave field strength radiated from MW radio stations were measured with a view to determining the effect of the variation of ground conductivity on ground wave. Also the ground conductivity was estimated in certain directions in the northern parts of Nigeria.

However, more work remains to be done in the areas undertaken in this research.

5.1 Suggestions for Further Work

The theoretical curves plotted in this work are for flat earth, but the distance at which earth curvature is negligible is not large. Therefore, efforts should be made to present the theoretical curves for a curved earth so that the propagation curves could cover large distances for design purposes.

The effect of the variation of ground conductivity on ground-wave field strength can be properly evaluated by taking measurements of the temporal variations of ground-wave

field strength radiated from MW radio stations over a period of 1 year. This is suggested as the next topic for research.

Research should be carried out to confirm the values of the ground conductivity obtained in the various directions in this research. Further work is necessary to deduce the ground conductivity in the remaining parts of the northern states of Nigeria which were not covered in this work. In fact there is need for extensive measurement of the ground conductivity to cover the entire radio propagation paths in Nigeria for improved communication services.

It is hoped that contour maps of the ground-wave field strength and ground conductivity will eventually be established for the whole country to serve as an easy reference in designing radio links.

Also, there is need to investigate the cause of the scattering of the plotted points in figure 4.6 when the propagation curves for 728 kHz were used. Two separate trips were undertaken from Samaru to Katsina and back and the scattering was observed for the two outings.

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APPENDIX 4

COMPUTER CALCOMP PROGRAMME FOR PLOTTING
THEORETICAL CURVES FOR THE BROADCAST
FREQUENCIES NOT EXCEEDING 756 kHz

```
OF MINNESOTA FORTRAN COMPILER (VERSION 5.0 - 77/03/24) ON THE CY72 UNDER N O S
      MNF,B=LGO,P=65000.
      C     THE PROGRAMME WAS PUNCHED ON CARDS
00016B      PROGRAM GR(INPUT,OUTPUT,TAPE30,TAPE5=INPUT,TAPE6=OUTPUT)
04171B      DIMENSION X(205),Y(205)
04171B      CALL PLOTS(0,0,30)
      C     SIX  FREQUENCIES WERE PUNCHED ON CARDS,EACH FREQUENCY ON A CARD
05025B      DO 105 K=1,6
05026B      CALL FACTOR(0.75)
05031B      CALL AXIS(0.,0.,13HDISTANCE (KM),-13,25.,0.,0.,8.)
05033B      CALL AXIS(0.,0.,49HELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT.
     1M),+49,26.,90.,22.,3.)
05035B      Y(197)=22.
05035B      Y(198)=3.
05037B      X(197)=0.
05040B      X(198)=8.
05041B      READ(5,100)F
      C     THE TRANSMITTER FREQUENCY(F) IS IN MHZ
05046B  100 FORMAT(F5.3)
05046B      WRITE(6,102)F
05052B  102 FORMAT(5X,F5.3)
05052B      WL=300./F
      C     WL IS WAVELENGTH IN METRES
05053B      DO 35 N=1,26
      C     N IS THE GROUND CONDUCTIVITY IN MMHO/M
05055B      R=(18.*FLOAT(N))/F
05057B      PERM=4.
      C     PERM IS THE RELATIVE PERMITTIVITY OF THE GROUND
05061B      S1=(PERM-1.)/R
05063B      S2=PERM/R
05064B      B1=ATAN(S1)
05070B      B2=ATAN(S2)
05072B      WRITE(6,103)S1,B1,S2,B2
05102B  103 FORMAT(3X,4(E16.5,8X))
05102B      DO 34 I=1,196
05103B      X(I)=5.+FLOAT(I-1)
      C     X(I) IS THE DISTANCE FROM THE TRANSMITTER IN KM
05105B      DX=X(I)*10**3
      C     D(X) IS THE DISTANCE FROM THE TRANSMITTER IN METRES
05106B      PI=3.1415927
05110B      P=(PI*DX*COS(B2)*COS(B2))/(R*WL*COS(B1))
      C     P IS A NUMERICAL DISTANCE
05123B      B=2.*B2-B1
      C     B IS THE PHASE CONSTANT
05126B      A1=(2.0+0.3*P)/(2.0+P+0.6*P*P)
05134B      EXP=2.7182818
05135B       A2=SQRT(P/2.0)*SIN(B)
05144B      PH6=0.625*P
05146B      TXP=EXP**PH6
05152B      A=A1-A2/TXP
      C     A IS THE FACTOR THAT CONSIDERS THE GROUND LOSSES
05154B      PW=1.0
```

```
      C       PW IS THE EFFECTIVE RADIATED POWER IN KILOWATT
5B            E1=150.*SQRT(PW)
0B            E=2.0*E1*(A/DX)*10**3
      C       E IS THE ELECTRIC FIELD IN MMV/M
4B            Y(I)=20.*ALOG10(E)+60.
      C       Y(I) IS THE ELECTRIC FIELD IN DB(REL. 1 MICRO-VOLT/M)
1B         34 CONTINUE
4B            DO 75 L=1,2
5B            CALL LINE(X,Y,196,1,0,2)
6B         75 CONTINUE
2B         35 CONTINUE
      C       SUB-PROGRAM FOR DRAWING THE VERTICAL LINES
5B            CALL PLOT(0.,0.,3)
7B            Y(28)=22.
7B            Y(29)=3.
1B            X(28)=0.
2B            X(29)=8.
3B            DO 20 N=1,25
5B            XX=8.+FLOAT((N-1)*8)
7B            DO 10 J=1,27
2B            X(J)=XX
2B            Y(J)=22.+FLOAT((J-1)*3)
6B         10 CONTINUE
6B            CALL LINE(X,Y,27,1,0,2)
2B         20 CONTINUE
      C       SUB-PROGRAM FOR DRAWING THE HORIZONTAL LINES
4B            CALL PLOT(0.,0.,3)
6B            Y(27)=22.
6B            Y(28)=3.
7B            X(27)=0.
1B            X(28)=8.

2B            DO 60 N=1,26
4B            YY=25.+FLOAT((N-1)*3)
7B            DO 65 J=1,26
1B            Y(J)=YY
1B            X(J)=FLOAT((J-1)*8)
3B         65 CONTINUE
5B            CALL LINE(X,Y,26,1,0,2)
7B         60 CONTINUE
1B            CALL PLOT(0.,0.,3)
3B            CALL PLOT(400.,0.,-3)
5B        105 CONTINUE
      C       SIX PLOTS ARE PRINTED SUCCESSIVELY
      C       EACH PLOT IS FOR EACH FREQUENCY
7B            CALL PLOT(0.,0.,99)
1B            WRITE(6,101)
4B        101 FORMAT(3X,*TEST PLOT COMPLETED*)
4B            STOP
5B            END
```

APPENDIX 2

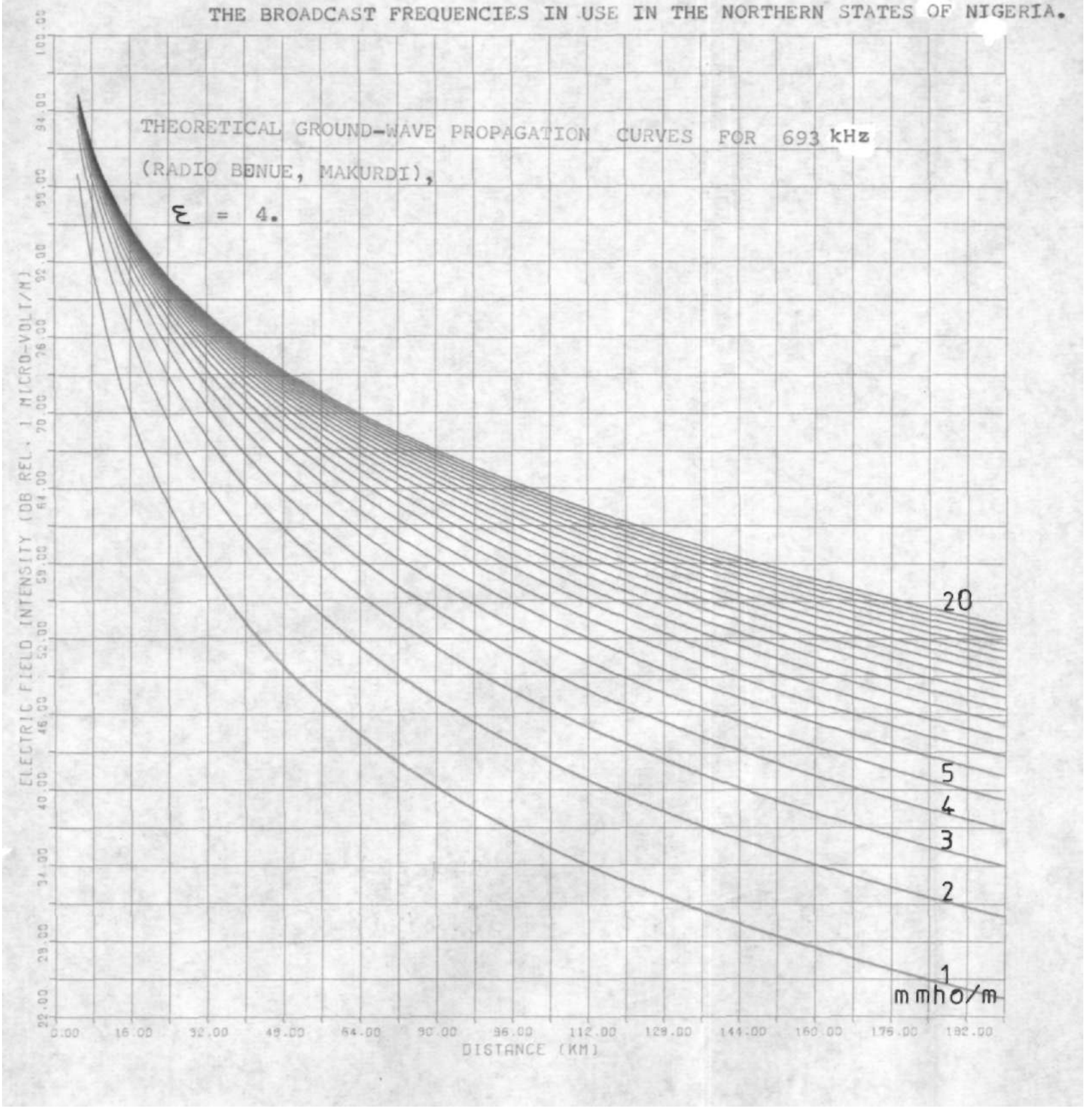
COMPUTER CALCOMP PROGRAMME FOR PLOTTING THEORETICAL CURVES FOR THE BROADCAST FREQUENCIES EXCEEDING 756 kHz.

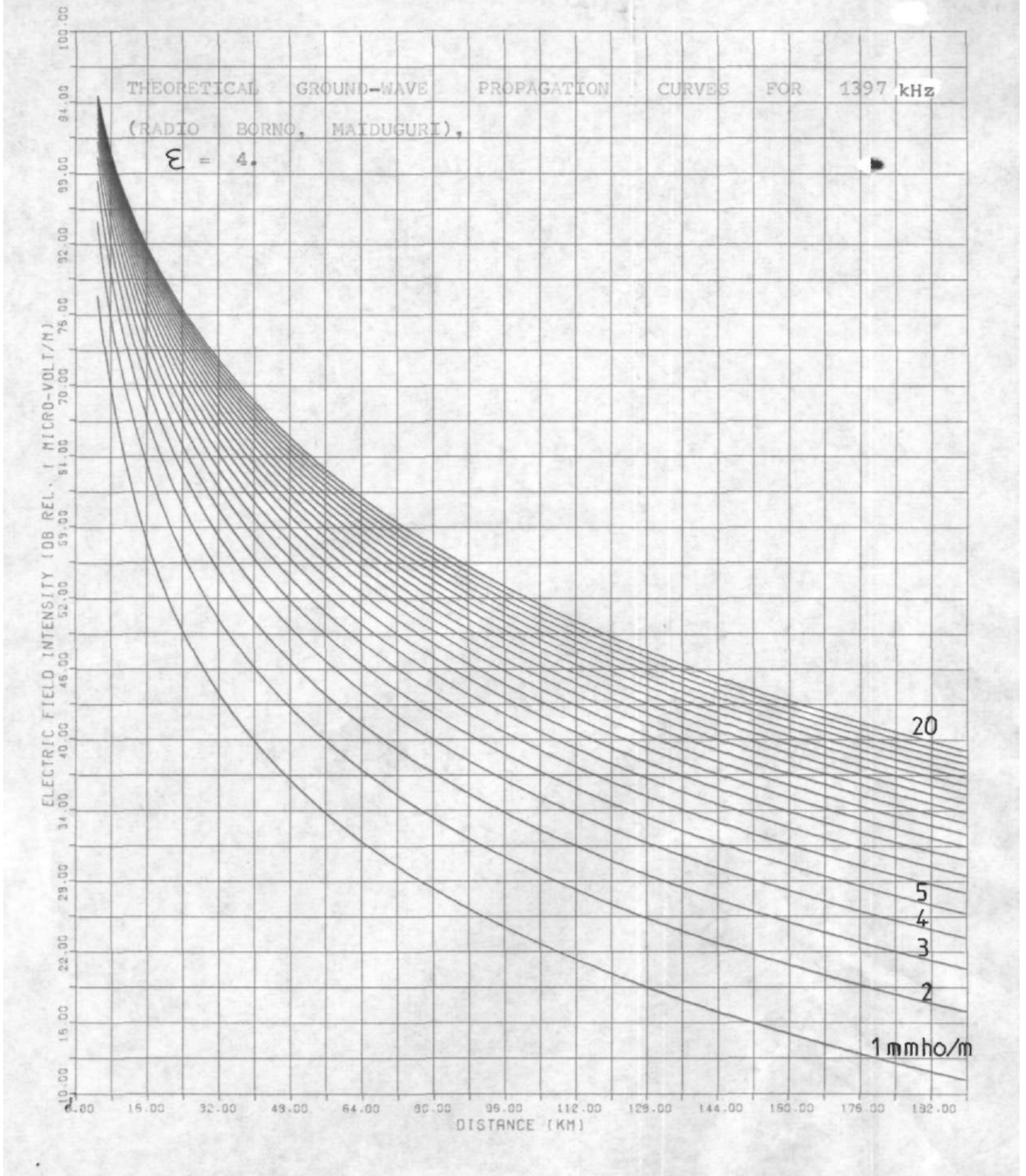
```
INNESOTA FORTRAN COMPILER (VERSION 5.0 - 77/03/24) ON THE CY72 UNDER  N O S 1.1
     MNF,B=LGO,P=65000.

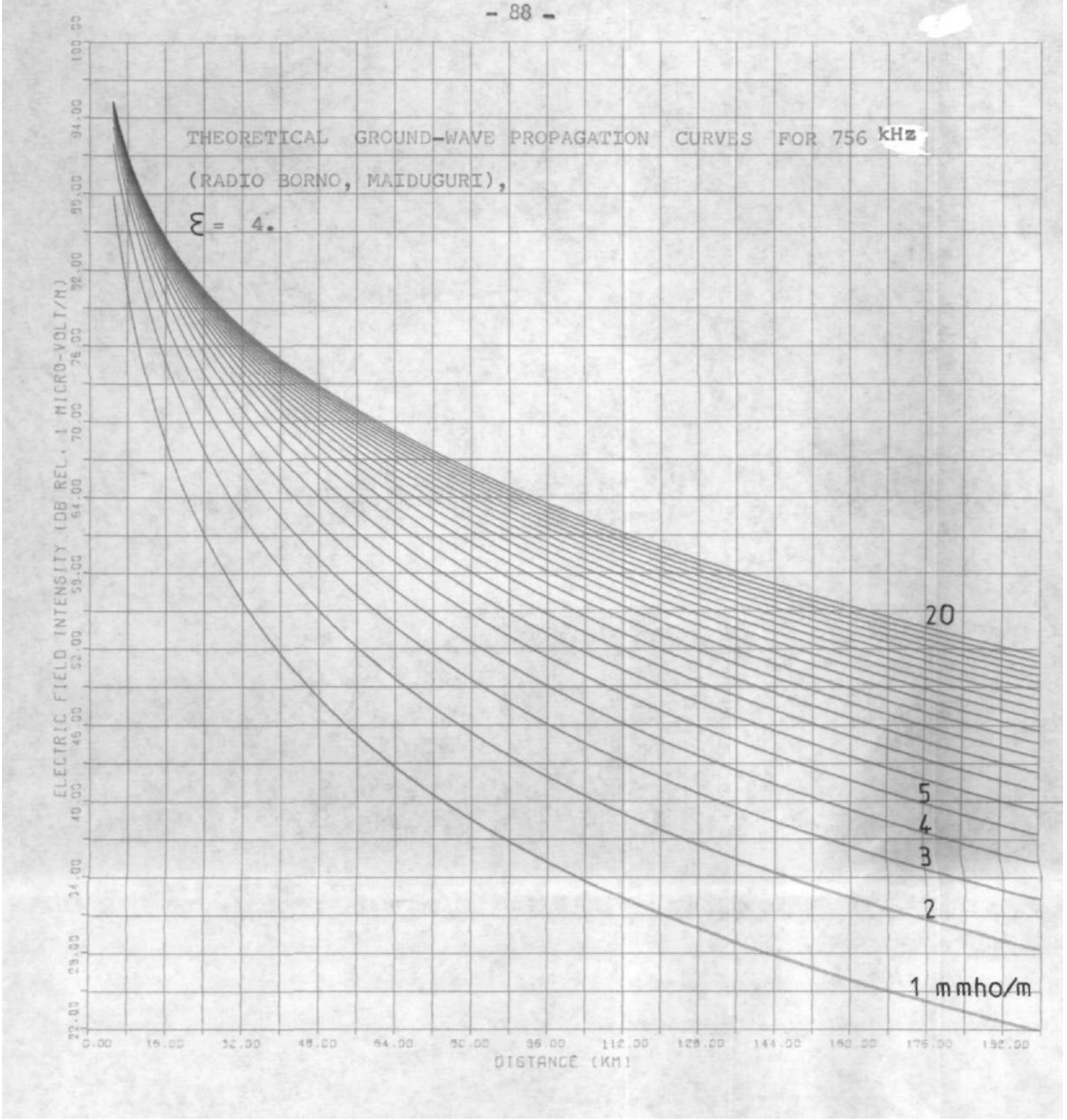
     C       THE PROGRAMME WAS PUNCHED ON CARDS
 0B          PROGRAM GR(INPUT,OUTPUT,TAPE27,TAPE5=INPUT,TAPE6=OUTPUT)
 1B          DIMENSION X(205),Y(205)
 1B          CALL PLOTS(0,0,27)
 5B          DO 105 K=1,4
 6B          CALL FACTOR(0.75)
 1B          CALL AXIS(0.,0.,13HDISTANCE (KM),-13,25.,0.,0.,8.)
 3B          CALL AXIS(0.,0.,49HELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/
            1M),+49,30.,90.,10.,3.)
 5B          Y(197)=10.
 5B          Y(198)=3.
 7B          X(197)=0.
 0B          X(198)=8.
 1B          READ(5,100)F
     C       THE TRANSMITTER FREQUENCY(F) IS IN MHZ
 6B      100 FORMAT(F5.3)
 6B          WRITE(6,102)F
 2B      102 FORMAT(5X,F5.3)
 2B          WL=300./F
     C       WL IS WAVELENGTH IN METRES
 3B          DO 35 N=1,20
     C       N IS THE GROUND CONDUCTIVITY IN MMHO/M
 5B          R=(18.*FLOAT(N))/F
 7B          PERM=4.
     C       PERM IS THE RELATIVE PERMITTIVITY OF THE GROUND
 1B          S1=(PERM-1.)/R
 3B          S2=PERM/R
 4B          B1=ATAN(S1)
 6B          B2=ATAN(S2)
 2B          WRITE(6,103)S1,B1,S2,B2
 2B      103 FORMAT(3X,4(E16.5,8X))
 2B          DO 34 I=1,196
 3B          X(I)=5.+FLOAT(I-1)
     C       X(I) IS THE DISTANCE FROM THE TRANSMITTER IN KM
 5B          DX=X(I)*1.E+3
     C       D(X) IS THE DISTANCE FROM THE TRANSMITTER IN METRES
 6B          PI=3.1415927
 0B          P=(PI*DX*COS(B2)*COS(B2))/(R*WL*COS(B1))
     C       P IS A NUMERICAL DISTANCE
 3B          B=2.*B2-B1
     C       B IS THE PHASE CONSTANT
 6B          A1=(2.0+0.3*P)/(2.0+P+0.5*P*P)
 4B          EXP=2.7182818
 5B           A2=SQRT(P/2.0)*SIN(B)
 4B          PH6=1.625*P
 6B          TXP=EXP**PH6
 2B          A=A1-A2/TXP
     C       A IS THE FACTOR THAT CONSIDERS THE GROUND LOSSES
 4B          PW=1.0
```

```
      C       PW IS THE EFFECTIVE RADIATED POWER IN KILOWATT
155B          E1=150.*SQRT(PW)
160B          E=2.0*E1*(A/DX)*10**3
      C       E IS THE ELECTRIC FIELD IN MMV/M
164B          Y(I)=20.*ALOG10(E)+60.
      C       Y(I) IS THE ELECTRIC FIELD IN DB(REL. 1 MICRO-VOLT/M)
171B       34 CONTINUE
174B          DO 75 L=1,2
175B          CALL LINE(X,Y,195,1,0,2)
200B       75 CONTINUE
202B       35 CONTINUE
      C       SUB-PROGRAM FOR DRAWING THE VERTICAL LINES
205B          CALL PLOT(0.,0.,3)
207B          Y(32)=10.
211B          Y(33)=3.
212B          X(32)=0.
213B          X(33)=8.
215B          DO 20 N=1,25
217B          XX=8.+FLOAT((N-1)*8)
222B          DO 10 J=1,31
222B          X(J)=XX
226B          Y(J)=10.+FLOAT((J-1)*3)
230B       10 CONTINUE
232B          CALL LINE(X,Y,31,1,0,2)
234B       20 CONTINUE
      C       SUB-PROGRAM FOR DRAWING THE HORIZONTAL LINES
236B          CALL PLOT(0.,0.,3)
236B          Y(27)=10.
240B          Y(28)=3.
241B          X(27)=0.
242B          X(28)=8.
244B          DO 60 N=1,30
247B          YY=13.+FLOAT((N-1)*3)
252B          DO 65 J=1,26
252B          Y(J)=YY
254B          X(J)=FLOAT((J-1)*8)
256B       65 CONTINUE
260B          CALL LINE(X,Y,26,1,0,2)
262B       60 CONTINUE
264B          CALL PLOT(0.,0.,3)
266B          CALL PLOT(40.,0.,-3)
      105    CONTINUE
      C       FOUR PLOTS ARE PRINTED SUCCESSIVELY
      C       EACH PLOT IS FOR EACH FREQUENCY
270B          CALL PLOT(0.,0.,99)
272B          WRITE(6,101)
275B      101 FORMAT(3X,*TEST PLOT COMPLETED*)
275B          STOP
276B          END
```

APPENDIX 3: THEORETICAL GROUND - WAVE PROPAGATION CURVES FOR THE BROADCAST FREQUENCIES IN USE IN THE NORTHERN STATES OF NIGERIA.




THEORETICAL GROUND-WAVE PROPAGATION CURVES FOR 1397 kHz
(RADIO BORNO, MAIDUGURI),
ε = 4.
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
DISTANCE (KM)
20
5
4
3
2
1 mmho/m


THEORETICAL GROUND-WAVE PROPAGATION CURVES FOR 756 kHz
(RADIO BORNO, MAIDUGURI),
ε = 4.
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
DISTANCE (KM)
20
5
4
3
2
1 mmho/m

THEORETICAL GROUND-WAVE PROPAGATION CURVES

FOR 1017kHz (GONGOLA STATE RADIO, YOLA)

$\varepsilon = 4.$

20

5

4

3

2

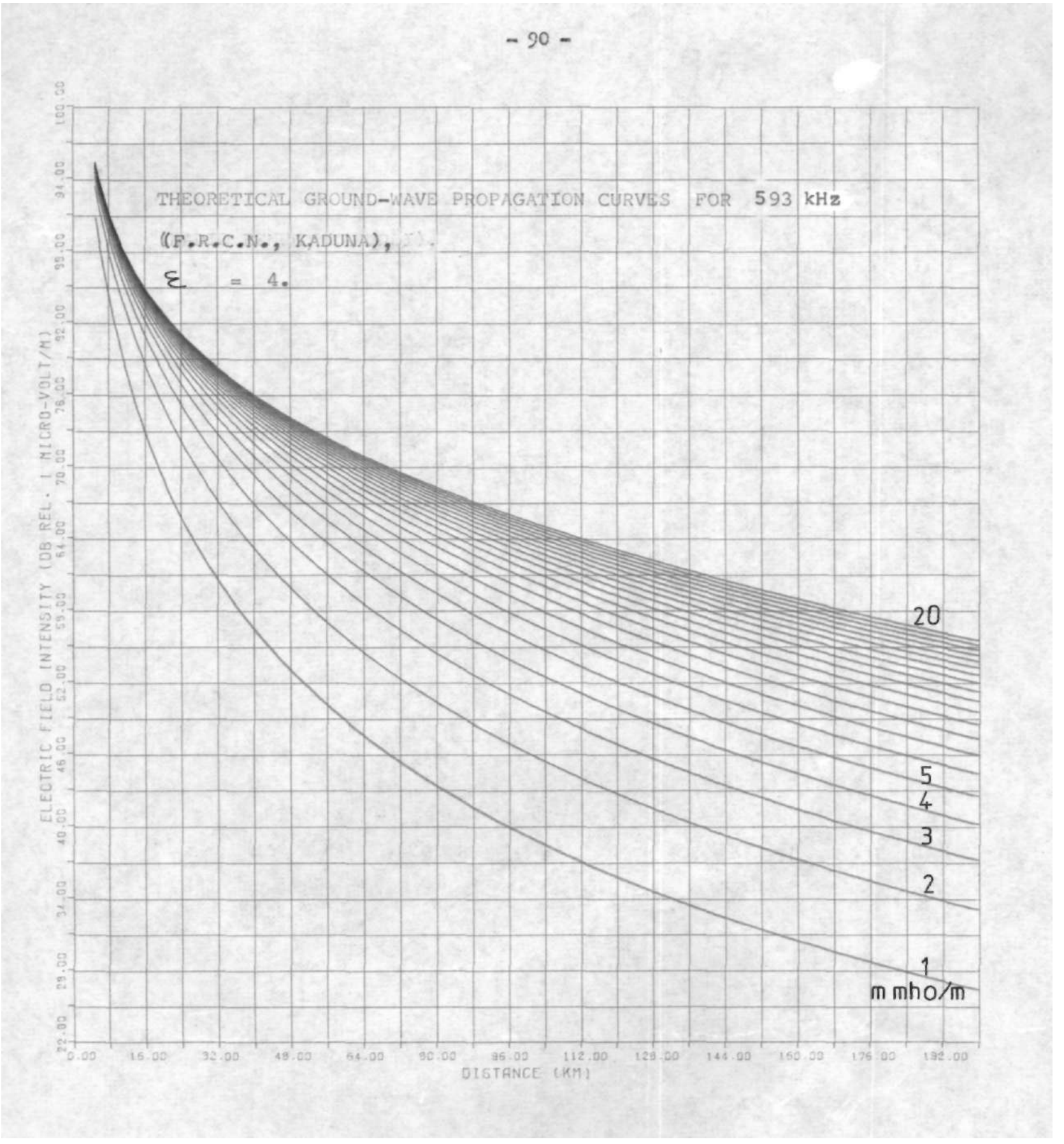
1 mmho/m

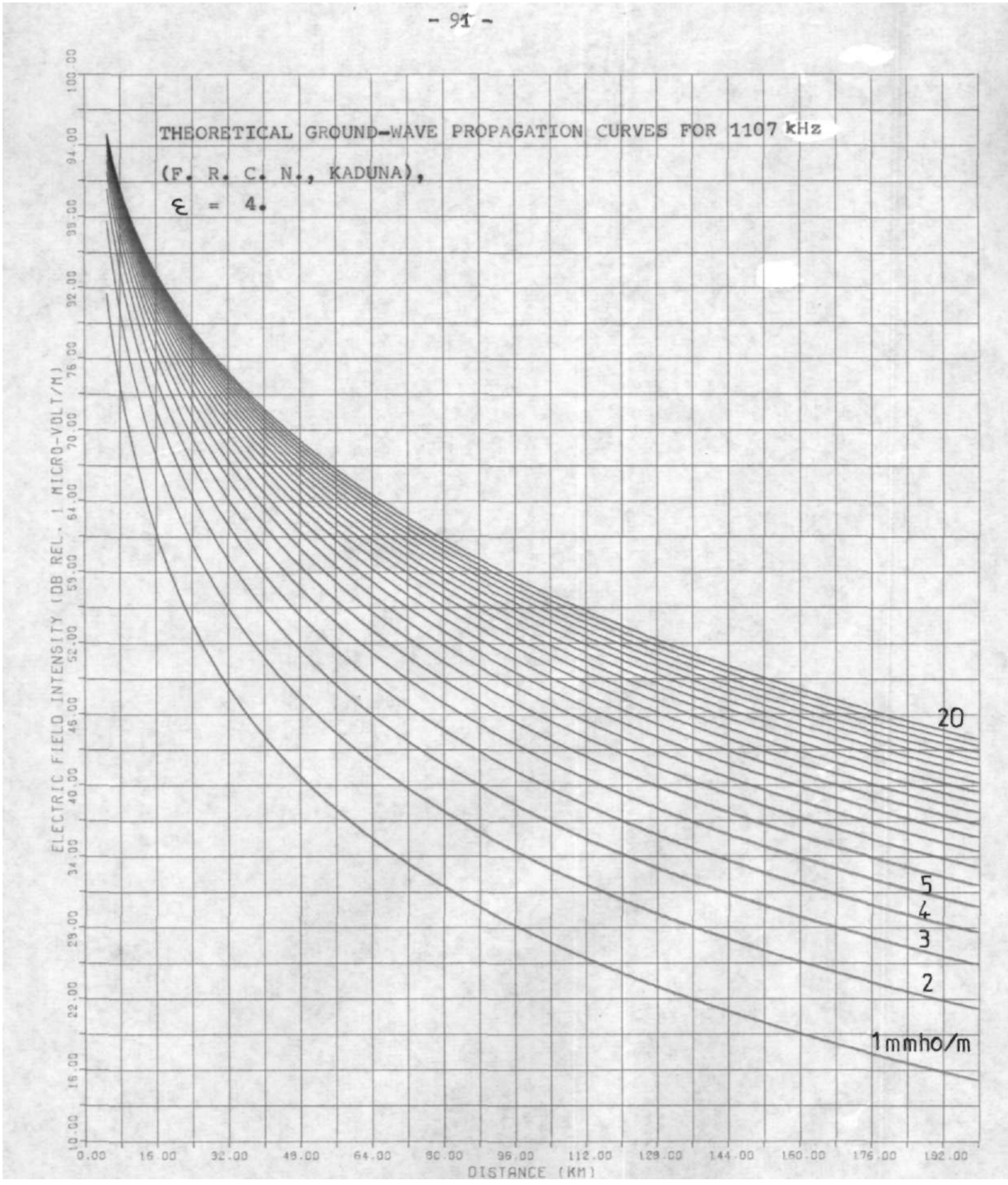
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)

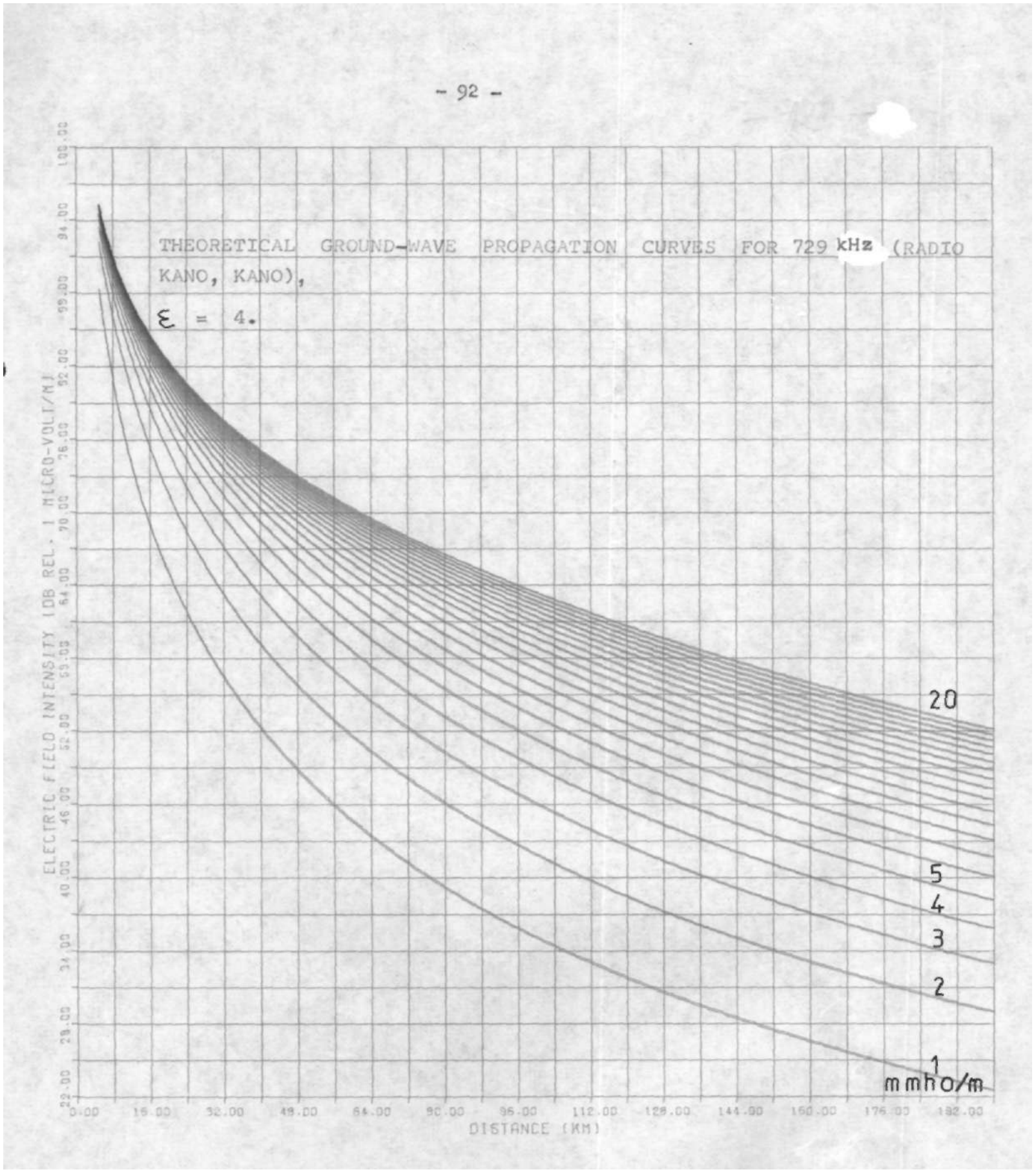
100.00 94.00 88.00 82.00 76.00 70.00 64.00 58.00 52.00 46.00 40.00 34.00 28.00 22.00 16.00 10.00

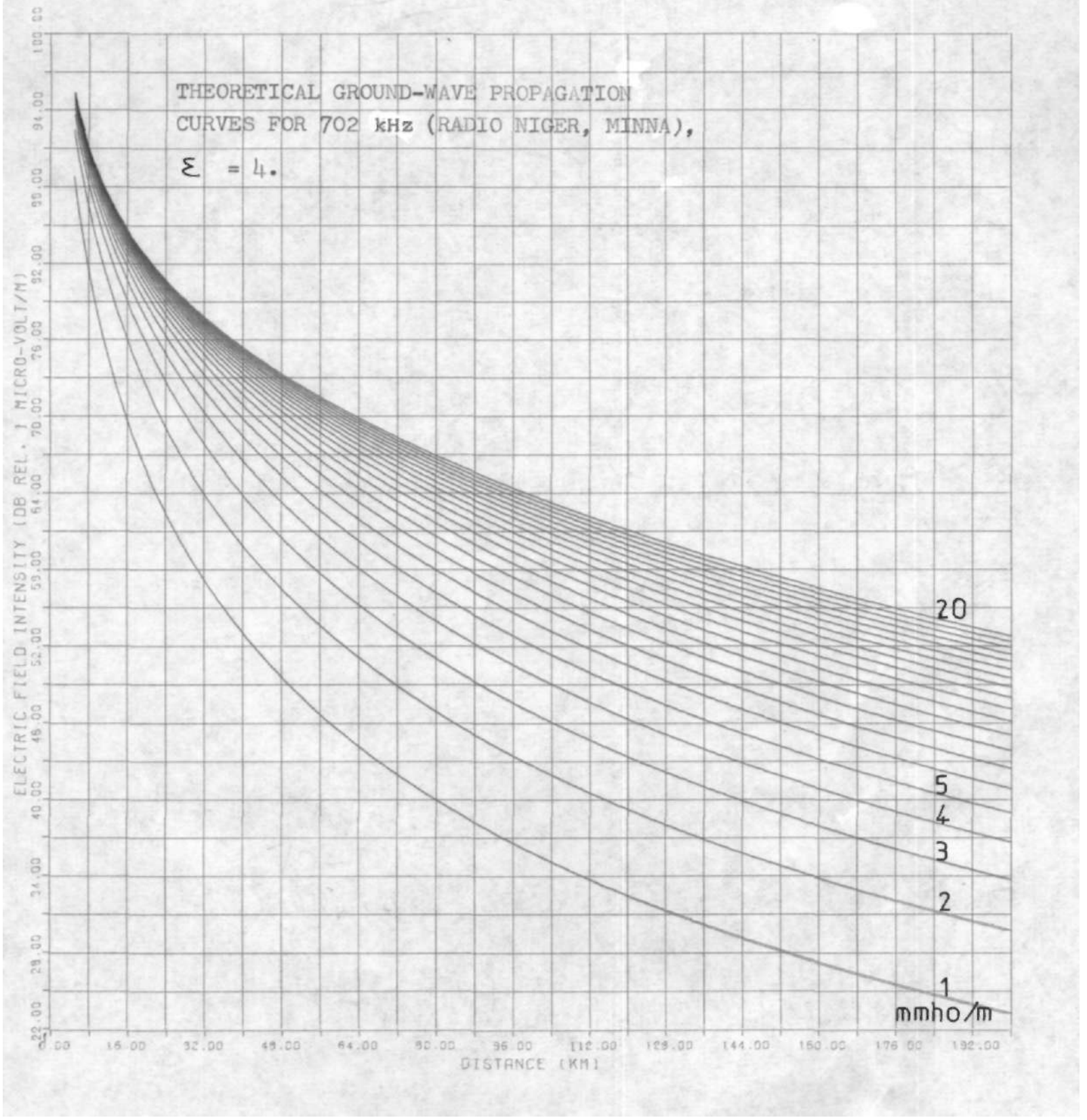
0.00 16.00 32.00 48.00 64.00 80.00 96.00 112.00 128.00 144.00 160.00 176.00 192.00

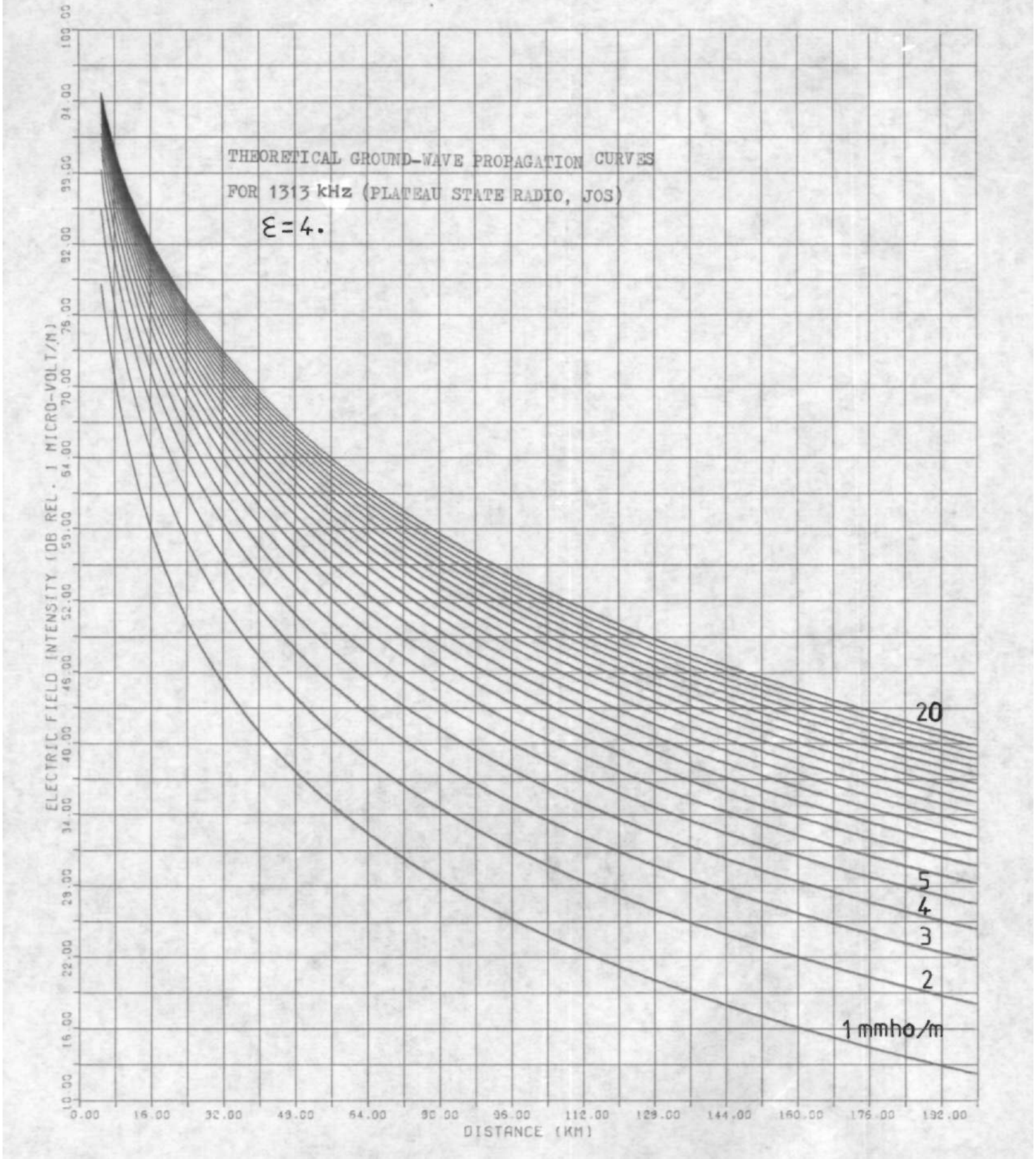
DISTANCE (KM)

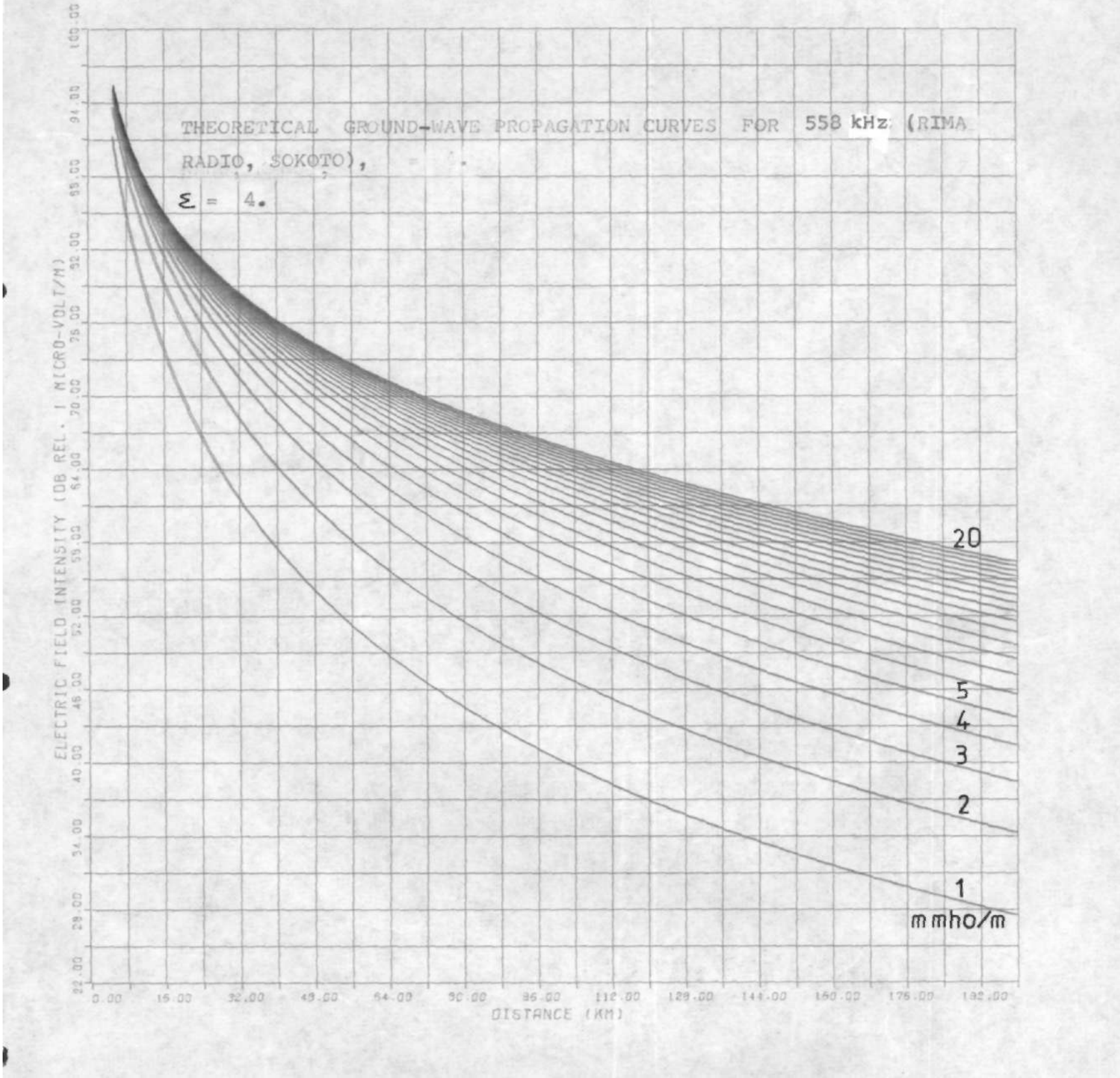

THEORETICAL GROUND-WAVE PROPAGATION CURVES FOR 593 kHz
(F.R.C.N., KADUNA),
ε = 4.
20
5
4
3
2
1
m mho/m
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
100.00
94.00
88.00
82.00
76.00
70.00
64.00
58.00
52.00
46.00
40.00
34.00
28.00
22.00
0.00
16.00
32.00
48.00
64.00
80.00
96.00
112.00
128.00
144.00
160.00
176.00
192.00
DISTANCE (KM)

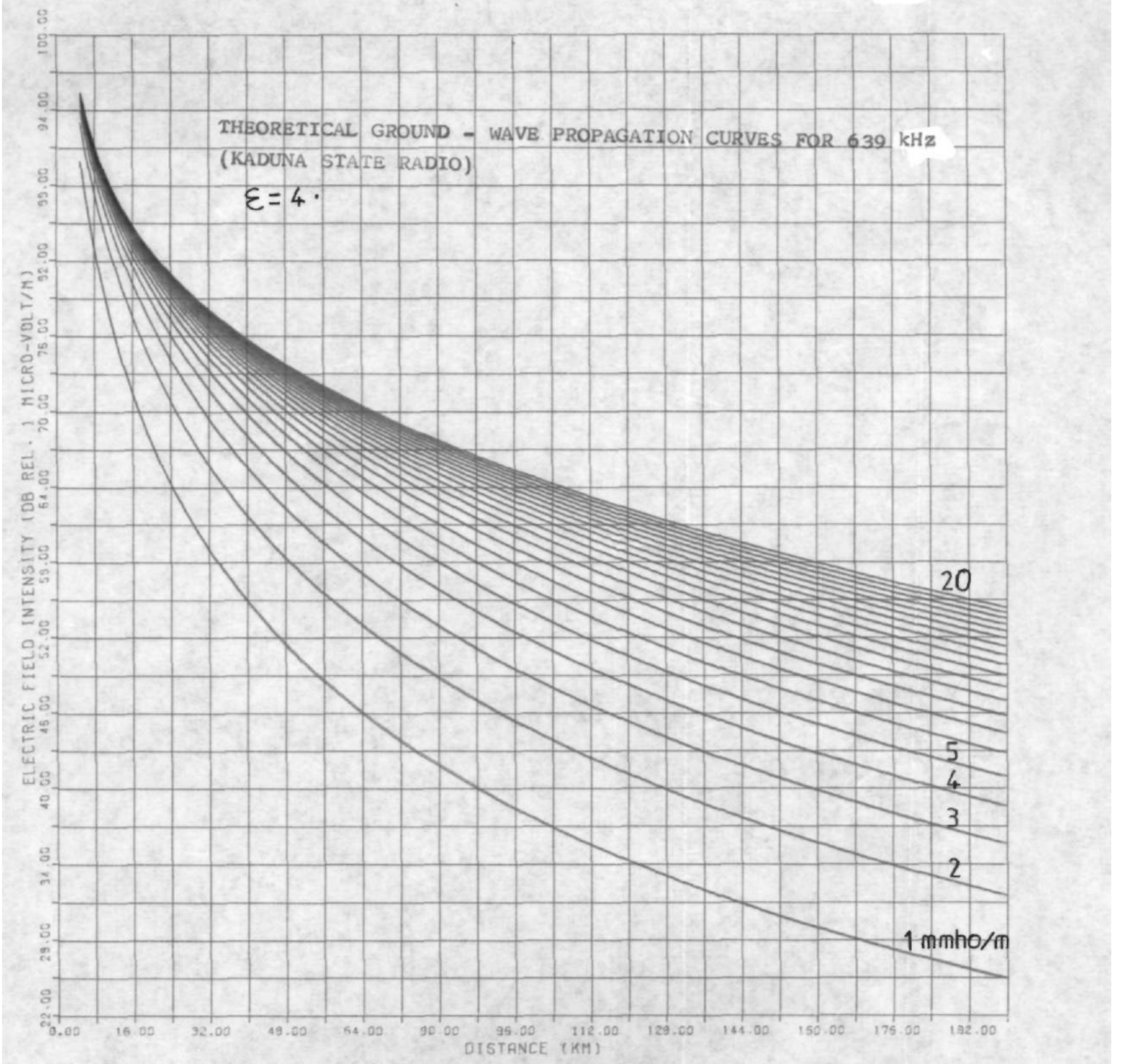

THEORETICAL GROUND-WAVE PROPAGATION CURVES FOR 1107 kHz
(F. R. C. N., KADUNA),
ε = 4.
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
100.00
94.00
88.00
82.00
76.00
70.00
64.00
58.00
52.00
46.00
40.00
34.00
28.00
22.00
16.00
10.00
0.00
16.00
32.00
48.00
64.00
80.00
96.00
112.00
128.00
144.00
160.00
176.00
192.00
DISTANCE (KM)
20
5
4
3
2
1mmho/m

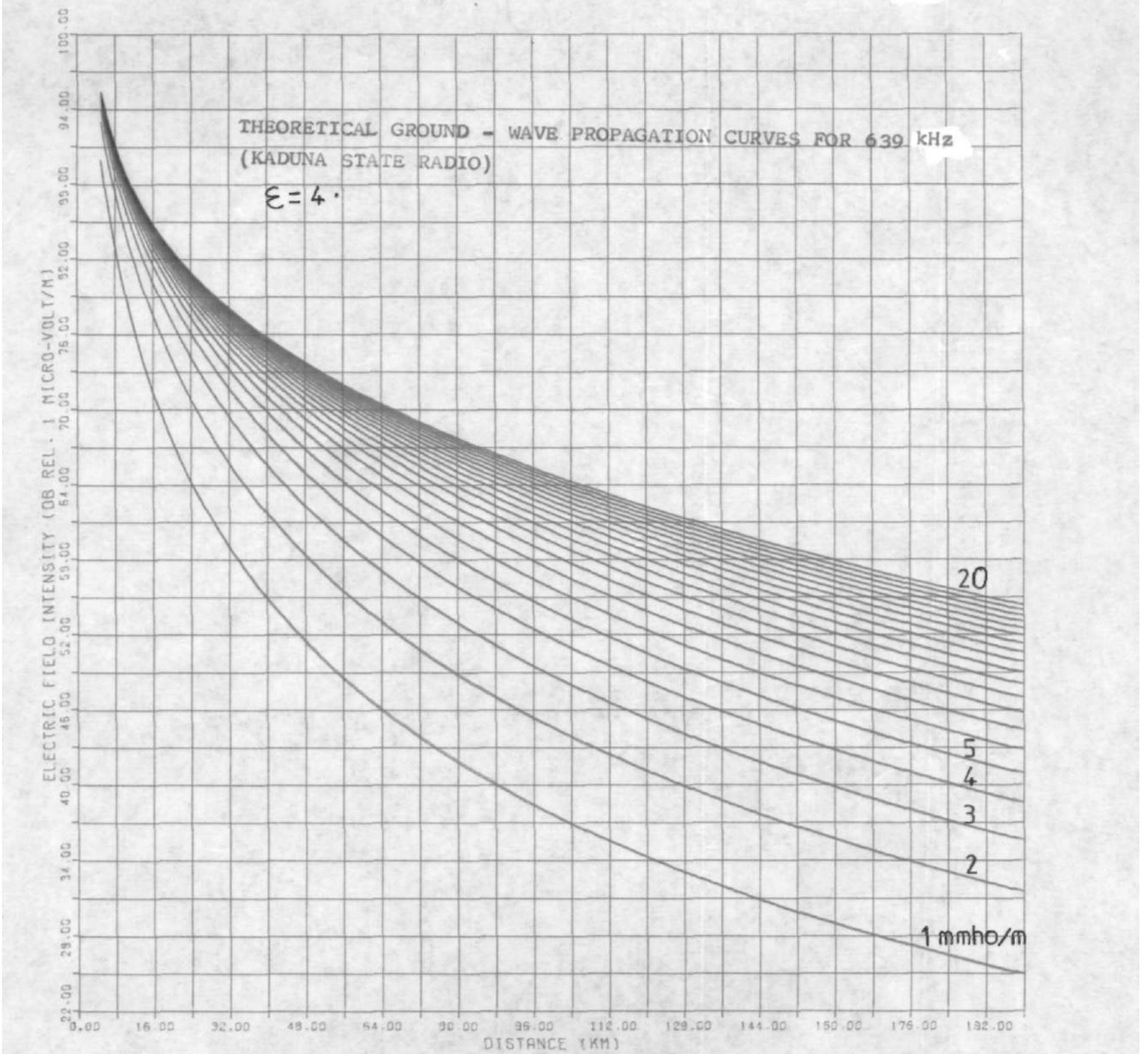

THEORETICAL GROUND-WAVE PROPAGATION CURVES FOR 729 kHz (RADIO KANO, KANO),
ε = 4.
20
5
4
3
2
1
mmho/m
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
DISTANCE (KM)
0.00
16.00
32.00
48.00
64.00
80.00
96.00
112.00
128.00
144.00
160.00
176.00
192.00
22.00
28.00
34.00
40.00
46.00
52.00
58.00
64.00
70.00
76.00
82.00
88.00
94.00
100.00


THEORETICAL GROUND-WAVE PROPAGATION
CURVES FOR 702 kHz (RADIO NIGER, MINNA),
Σ = 4.
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
DISTANCE (KM)
20
5
4
3
2
1
mmho/m


THEORETICAL GROUND-WAVE PROPAGATION CURVES
FOR 1313 kHz (PLATEAU STATE RADIO, JOS)
ε = 4.
20
5
4
3
2
1 mmho/m
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
DISTANCE (KM)
10.00
16.00
22.00
28.00
34.00
40.00
46.00
52.00
58.00
64.00
70.00
76.00
82.00
88.00
94.00
100.00
0.00
16.00
32.00
48.00
64.00
80.00
96.00
112.00
128.00
144.00
160.00
176.00
192.00


THEORETICAL GROUND-WAVE PROPAGATION CURVES FOR 558 kHz (RIMA RADIO, SOKOTO),
Σ = 4.
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
DISTANCE (KM)
20
5
4
3
2
1
mmho/m


THEORETICAL GROUND - WAVE PROPAGATION CURVES FOR 639 kHz
(KADUNA STATE RADIO)
ε = 4·
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
DISTANCE (KM)
20
5
4
3
2
1 mmho/m
100.00
94.00
88.00
82.00
76.00
70.00
64.00
58.00
52.00
46.00
40.00
34.00
28.00
22.00
0.00
16.00
32.00
48.00
64.00
80.00
96.00
112.00
128.00
144.00
160.00
176.00
192.00


THEORETICAL GROUND - WAVE PROPAGATION CURVES FOR 639 kHz
(KADUNA STATE RADIO)
ε = 4·
ELECTRIC FIELD INTENSITY (DB REL. 1 MICRO-VOLT/M)
100.00
94.00
88.00
82.00
76.00
70.00
64.00
58.00
52.00
46.00
40.00
34.00
28.00
22.00
0.00
16.00
32.00
48.00
64.00
80.00
96.00
112.00
128.00
144.00
160.00
176.00
192.00
DISTANCE (KM)
20
5
4
3
2
1 mmho/m

APPENDIX 4.1 : MEASURED GROUND-WAVE FIELD STRENGTH IN DIFFERENT DIRECTIONS IN NORTHERN PARTS OF NIGERIA.

4.1 A : SAMARU/KANO Rd. Junction - Hunkuyi - - Kano.

4.1 B : Kaduna - Sabon BirninGwari - Tegina

4.1 C : Kaduna - Abuja - Minna

4.1 D : Kaduna - Kufana - Kafanchan - Saminaka/Lere Rd. Junction - - Katabu.

4.1 E : Shika - Malumfashi - Katsina - Dutsinma - Kankara.

4.1 F : Shika - Funtua - Chafe - Sokoto.

APPENDIX 4.1 A_1

DATE: 27/6/81 LOCATIONS	FROM KADUNA JAJI - 593 kHz		RADIO NIGER, MINNA METUNBI - 702 kHz	
	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
KANO	165	51.1	338	-
KURA	141	54.8	314	32.5
DAKATSAILE	-	58.5	-	35.1
KAFIN MAIYAKI	98	60.0	272	35.1
KANO/IKARA RD. JUNCTION	-	-	266	37.6
MAKARFI	70	67.8	242	36.9
HUNKUYI	52	71.8	219	39.4
SAMARU/KANO RD.JUNCTION	37	75.8	208	40.0

Appendix 4.1 A_1 (Continued)

DATE: 27/6/81	KANO STATE RADIO JOGANNA - 728 kHz		RIMA RADIO SOKOTO SHUNI - 557 kHz	
LOCATIONS	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
KANO	26	93.5	363	44.7
KURA	45	84.9	365	43.4
DAKATSALLE	-	83.7	-	42.9
KAFIN MAIYAKI	88	74.8	348	43.6
KANO/IKARA RD. JUNCTION	98	63.5	348	43.8
MAKARFI	119	63.0	330	40.0
HUNKUYI	144	58.7	316	44.8
SAMARU/KANO RD.JUNCTION	152	57.7	326	39.6

Appendix 4.1 A_2

DATE: 27/6/81	FRCN KADUNA JAJI - 593 kHz		KANO STATE RADIO JOGANDA - 728 kHz	
LOCATIONS	DISTANCE (km)	NORMALIZED FIELD STRENGTH (dB)	DISTANCE (km)	NORMALIZED FIELD STRENGTH (dB)
KANO	165	41.1	26	76.5
KURA	141	44.8	45	67.9
KAFIN MAIYAKI	98	50.0	88	57.8
KANO/IKARA RD. JUNCTION	89	-	98	46.5
MAKARFI	70	57.8	119	46.0
HUNKUYI	52	61.8	144	41.7
SAMARU/KANO RD. JUNCTION	337	65.8	152	40.7

Appendix 4.1 A_3

DATE: 20/8/81	FRCN KADUNA JAJI - 593 kHz		RADIO NIGER MINNA METUNBI - 702 kHz	
LOCATIONS	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
SAMARU/KANO RD. JUNCTION	37	73.8	208	41.6
HUNKUYI	52	70.5	219	40.0
MAKARFI	70	67.6	242	38.7
KANO/IKARA RD. JUNCTION	89	68.3	266	39.6
KAFIN MAIYAKI	98	61.4		
KURA	141	54.8		
KANO/RANO RD. JUNCTION	153	52.8		
KANO	165	45.3		

Appendix 4.1 A_3 (Contd.)

DATE: 20/8/81	KANO STATE RADIO JOGANNA - 729 kHz	
LOCATIONS	DISTANCE (km)	FIELD STRENGTH (dB)
SAMARU/KANO RD. JUNCTION	152	56.9
HUNKUYI	144	57.8
MAKARFI	119	60.0
KANO/IKARA RD. JUNCTION	98	63.0
KAFIN MAIYAKI	88	-
KURA	45	-
KANO/RANO RD. JUNCTION	33	80.8
KANO	26	82.8

Appendix 4.1 A_4

DATE: 20/8/81	FRCN KADUNA JAJI - 593 kHz		KANO STATE RADIO JOGANNA - 729 kHz	
LOCATIONS	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)
SAMARU/KANO RD. JUNCTION	37	63.8	152	39.9
HUNKUYI	52	60.5	144	40.8
MAKARFI	70	57.6	119	43.0
KANO/IKARA RD. JUNCTION	89	-	98	46.0
KAFIN MAIYAKI	98	51.4	88	-
KURA	141	44.8	45	-
KANO/RANO RD. JUNCTION	153	42.8	33	63.8
KANO	165	35.3	26	65.8

Appendix 4.1 B_1

DATE: 25/8/81	RIMA RADI SOKOTO SHUNI - 557 kHz		FRCN KADUNA JAJI - 593 kHz	
LOCATIONS	Distance (km)	Field Strength (dB)	Distance (km)	Field Strength (dB)
KADUNA (NEAR KAWO)	353	34.5	29	75.8
BUKUKU	330	38.5	44	71.7
SABON BIRNINGWARI	286	42.0	113	48.4
KUSHERIKI	292	43.2	127	46.6

Appendix 4.1 B_1 (Contd.)

DATE: 25/8/81	RADIO NIGER, MINNA METUNBI - 702 kHz		KANO STATE RADIO JOGANNA - 729 kHz	
LOCATIONS	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
KADUNA (NEAR KAWO)	140	58.8	215	44.6
BURUKU	130	50.9	228	44.4
SABON BIRNINGWARI	114	55.3	283	35.0
KUSHERIKI	103	55.7	300	31.6

Appendix 4.1 B_2

DATE: 25/8/81	FRCN KADUNA JAJI - 593 kHz		RADIO NIGER, MINNA METUNBI - 702 kHz	
LOCATIONS	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)
KADUNA (NEAR KAWO)	29	65.8	140	48.8
BURUKU	44	61.7	130	40.9
SABON BIRNIN GWARI	113	38.4	114	45.3
KUSHERIKI	127	36.6	103	45.7

Appendix 4.1 B_3

DATE: 11/1/82	RIMA RADIO, SOKOTO SHUNI - 558 kHz		FRCN KADUNA JAJI - 593 kHz	
LOCATIONS	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
SAMARU - ZARIA	333	41.9	39	77.3
ZANGWAN AYA	-	40.8	12	88.5
RIGACHIKUN	346	38.1	23	81.8
KAWO - KADUNA	353	33.6	30	78.5
BURUKU	330	37.5	41	71.8
SABON BIRNINGWARI	286	42.9	113	48.3
KUSHERIKI	292	44.5	127	46.8
PANDOGARI	301	42.3	151	45.8
KAGARA	318	38.5	159	40.0
TEGINA	331	37.3	171	39.6

Appendix: 4.1 B_3 (Continued)

DATE: 11/1/82	RADIO NIGHE , MINNA METUNBI - 702 kHz		KANO STATE RADIO JOGANNA - 729 kHz	
LOCATIONS	Dist. (km)	Field Strength (DB)	Dist. (km)	Field Strength (DB)
SAMARU - ZARIA	203	42.8	154	58.1
ZANGON AYA	-	43.1	174	54.4
RIGACHIKUN	152	48.0	206	48.6
KANO - KADUNA	140	48.6	212	46.0
BURUKU	130	49.7	224	45.0
SABON BIRNIN GWARI	114	54.3	282	35.8
KUSHERIKI	103	55.3	299	31.4
PANDOGARI	92	60.8	329	32.7
KAGARA	75	60.0	337	28.3
TEGINA	65	59.6	352	28.6

Appendix 4.1 B_4

DATE: 11/1/82	FRCN KADUNA JAJI - 593 kHz		RADIO NIGER MINNA METUNBI - 702 kHz	
LOCATIONS	Distance (km)	Normalised Field Strength (dB)	Distance (km)	Normalised Field Strength (dB)
SAMARU - ZARIA	39	67.3	203	32.8
RIGACHIKUN	23	71.8	152	38.0
KAWO - KADUNA	30	68.5	140	38.6
BURUKU	41	61.8	130	39.7
SABON BIRNIN GWARI	113	38.3	114	44.3
KUSHERIKI	127	36.8	103	45.3
PANDOGARI	151	35.8	92	50.8
KAGARA	159	30.0	75	50.0
TEGINA	171	29.6	65	49.6

Appendix 4.1 C_1

DATE: 20/6/81	FRCN KADUNA JAJI - 593 kHz		RADIO NIGER, MINNA METUNBI - 702 kHz	
LOCATIONS	Distance (km)	Field Strength (dB)	Distance (km)	Field Strength (dB)
KADUNA (NEAR KAWO)	35	77.1	140	47.6
DOKA	102	53.4	92	52.9
RIVER DINYA BRIDGE	124	49.7	82	52.9
RIVER GURARA BRIDGE	149	46.6	76	55.0
ABUJA/SULEJA RD.JUNCTION	186	39.6	83	56.9
IZOM	184	-	64	64.3
BIDA/MINNA RD. JUNCTION (NEAR IZOM)			61	66.4
KWAKUTI			47	67.4
PAIKO/LAPAI RD. JUNCTION			21	85.6

Appendix 4.1 C_1 (Continued)

DATE: 20/6/81 LOCATIONS	RIMA RADIO, SOKOTO SHUNI - 557 kHz		KANO STATE RADIO, JOGANNA - 728 kHz	
	Distance (km)	Field Strength (dB)	Distance (km)	Field Strength dB)
KADUNA (NEAR KAWO)	353	36.1	218	46.6
DOKA	-	32.9	277	37.8
RIVER DINYA BRIDGE	-	28.6	299	-
RIVER GURARA BRIDGE	-	26.4	323	30.9
ABUJA/SULEJA RD. JUNCTION			358	-
IZOM			361	-
BIDA/MINNA RD. JUNCTION (NEAR IZOM)				
KWAKUTI				
PAIKO/LAPAI RD. JUNCTION				

Appendix 4.1 C_2

DATE: 20/6/81 LOCATIONS	FROM KADUNA JAJI - 593 kHz		RADIO NIGER, MINNA METUNBI - 702 kHz	
	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)
KADUNA (NEAR KAWO)	35	67.1	140	37.6
DOKA	102	43.4	92	42.9
R. DINYA BRIDGE	124	39.7	82	42.9
R. GURARA "	149	36.6	76	45.0
ABUJA/SULEJA RD. JUNCTION	186	29.6	83	46.9
IZOM			64	54.3
BIDA/MINNA RD. JUNCTION (NEAR IZOM)			61	56.4
KWAKUTI			47	57.4
PAIKO/LAPAI RD. JUNCTION			21	75.6

Appendix 4.1 C_3

(By Train)

DATE: 15/8/81 LOCATIONS	FRCN KADUNA JAJI - 593 kHz		RADIO NIGER, MINNA METUNBI - 702 kHz	
	Distance (km)	Field Strength (dB)	Distance (km)	Field Strength (dB)
KADUNA RAILWAY STATION	35	70.9	140	48.8
BAKIN KASUWA "	67	61.6	109	52.4
GODANI "	88	53.8	87	59.3
KUCHI	109	48.8	65	65.1
GUNI	131	49.5	49	73.1
GWADA	145	45.8	34	84.7
MINNA	175	40.2	-	100.0

Appendix 4.1 C_4

(BY TRAIN)

DATE: 15/8/81 LOCATIONS	FRCN KADUNA JAJI - 593 kHz		RADIO NIGER, MINNA METUNBI - 702 kHz	
	DISTANCE (dB)	NORMALIZED FIELD STRENGTH (dB)	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)
KADUNA RAILWAY STATION	35	60.9	140	38.8
BAKIN KASUWA " "	67	51.6	109	42.4
GODANI " "	88	43.8	87	49.3
KUCHI " "	109	38.8	65	55.1
GUNI " "	131	39.5	49	63.1
GWADA " "	143	35.8	-	-
MINNA " "	175	30.2	-	-

Appendix 4.1 D_1

DATE: 22/8/81 23/8/81 LOCATIONS	RIMA RADIO SOKOTO SHUNI - 557 kHz		FRCN KADUNA JAJI - 593 kHz	
	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
KADUNA (NEAR KUJAMA)	356	34.3	44	72.8
KUJAMA RD. JUNCTION	370	35.1	58	73.8
KUFANA	-	33.1	63	63.9
IDON	420	30.2	88	57.1
KURMIN BIRI RAILWAY CROSSING	-	28.0	99	54.1
KACHIA	443	28.9	113	53.1
KAFANCHAN RAILWAY CROSSING	490	23.2	158	42.3
KAGORO	496	26.2	162	47.2
SAMARU	-	25.7	149	47.0
DAMAKASUWA	-	27.4	144	47.6
MARIRI	-	27.3	138	48.4
GARUN KURAMA	-	25.1	133	50.1
LERE	-	-	122	54.0
SAMINAKA/LERE RD. JUNCTION	-	-	128	52.8
KUDARU	-	29.1	101	52.4
PAMBEGUWA	-	35.3	80	63.4
GAMAGIRA	373	-	37	76.1
IGABI/KATABU RD. JUNCTION	-	-	14	88.2
KATABU	-	-	15	84.6

Appendix 4.1 D. (Contd.)

DATE: 22/8/81 23/8/81 LOCATIONS	RADIO NIGER, MINNA METUNBI - 702 kHz		KANO STATE RADIO JOGANNA - 729 kHz	
	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
KADUNA (NEAR KUJAMA)	134	50.8	226	46.2
KUJAMA RD. JUNCTION	153	46.6	210	44.8
KUFANA	-	45.8	220	45.2
IDON	160	46.4	231	42.1
KURMIN BIRI RAILWAY CROSSING	-	42.6	234	42.4
KACHIA	157	45.1	253	39.9
KAFANCHAN RAILWAY CROSSING	192	36.9	274	37.8
KAGORO	200	41.4	270	41.7
SAMARU	-	38.1	255	45.0
DAMAKASUWA	-	36.9	236	48.6
MARIRI	-	38.5	224	49.6
GARUN KURAMA	-	38.5	208	50.7
LERE	-	38.6	184	51.1
SAMINAKA/LERE RD. JUNCTION	-	38.9	179	50.6
KUDARU	-	30.6	157	49.8
PAMBEGUWA	-	40.6	159	43.0
GAMAGIRA	189	44.5	175	52.7
IGABI/KATABU RD. JUNCTION	-	44.5	182	53.1
KATABU	-	46.2	199	47.6

Appendix 4.1 D_2

DATE : 22/8/81 & 23/8/81 LOCATIONS	FRCN KADUNA JAJI - 593 kHz	
	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)
KADUNA (NEAR KUJAMA)	44	62.8
KUJAMA RD. JUNCTION	58	63.8
KUFANA	63	53.9
IDON	88	47.1
KURMINBIRI RAILWAY CROSSING	99	44.1
KACHIA	113	43.1
KAFANCHAN RAILWAY CROSSING	159	32.3
KAGORO	162	37.2
SAMARU	149	37.0
DAMAKASUWA	145	37.6
MARIRI	138	38.4
GARUN KURAMA	133	40.1
LERE	122	44.0
SAMINAKA/LERE RD. JUNCTION	128	42.8
KUDARU	101	42.4
PAMBEGUWA	80	53.4
GAMAGIRA	37	66.1
IGABI/KATABU RD. JUNCTION	-	-
KATABU	-	-

Appendix 4.1 E_1

DATE: 6/6/81	FRCN KADUNA JAJI - 593 kHz		RIMA RADIO SOKOTO SHUNI - 557 kHz		KANO STATE RADIO JOGANNA - 728 kHz	
LOCATIONS	DIST. (km)	FIELD STRENGTH (dB)	DIST. (km)	FIELD SRENGTH (dB)	DIST. (km)	FIELD STRENGTH (dB)
SHIKA	42	73.3	311	29.5	158	55.8
GIWA RD. JUNCTION	49	71.6	295	46.0	164	55.0
MASKA	62	68.0	285	46.4	169	54.8
FUNTUA	80	53.5	270	49.2	165	56.9
BAKORI	82	64.1	278	49.1	151	60.0
JARGABA RD. JUNCTION	91	59.1	-	49.5	143	60.0
KARFI	99	59.8	-	51.4	135	60.8
MALUMFASHI	105	58.1	284	50.1	126	61.6
GORA	121	57.0	284	51.4	116	66.4
DAYI	130	55.0	282	50.2	113	66.4
MUSAWA RD. JUNCTION	144	53.4	273	52.3	108	66.0
KANO " " (NEAR YASHI)	172	50.9	291	48.3	96	65.1
KANKIYA " "	191	47.0	280	50.5	112	60.2
BINDAWA " " (NEAR CHERANCHI)	202	44.6	274	50.9	128	58.5
RIMI RD. JUNCTION	222	41.4	260	47.3	144	55.3
KATSINA	240	38.3	252	50.2	161	51.1
BATAGARAWA RD. JUNCTION	231	41.1	-	47.2	156	52.7
KURFI	203	46.8	-	53.2	151	58.1
DUTSIN-MA	179	49.8	245	52.3	141	60.7
KANKARA	123	54.8	256	49.5	144	60.4

Appendix 4.1 E_2

DATE: 6/6/81 LOCATIONS	FRCN KADUNA JAJI - 593 kHz		KANO STATE RADIO JOGANNA - 728 kHz	
	DISTANCE (km)	NORMALIZED FIELD STRENGTH (dB)	DISTANCE (km)	NORMALIZED FIELD STRENGTH (dB)
SHIKA	42	63.3	158	38.8
GIWA RD. JUNCTION	49	61.6	164	38.0
MASKA	62	58.0	169	37.8
FUNTUA	80	53.5	165	39.9
BAKORI	82	54.1	151	43.0
JARGABA RD. JUNCTION	91	49.1	143	43.0
KARFI	99	49.8	135	43.8
MALUMFASHI	105	48.1	126	44.6
GORA	121	47.0	116	49.4
DAYI	130	45.0	113	49.4
MUSAWA RD. JUNCTION	144	43.4	108	49.0
KANO RD. JUNCTION NEAR YASHI	172	40.9	96	48.1
KANKIYA RD. JUNCTION	191	37.0	112	43.2
BINDAWA " " (NEAR CHERANCHI)	202	-	128	41.5
RIMI " "	222	-	144	38.3
KATSINA	240	-	161	34.1
BATAGARAWA RD. JUNCTION	231	-	156	35.7
KURFI	203	-	151	41.4
DUTSIN-MA	179	39.8	141	43.7
KANKARA	123	44.8	144	43.4

Appendix 4.1 E_3

DATE: 29/8/81	RIMA RADIO SOKOTO SHUNI - 557 kHz		FRCN KADUNA JAJI - 593 kHz	
LOCATIONS	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
SHIKA	311	41.6	42	73.7
GIWA RD. JUNCTION	295	46.4	49	72.1
MASKA	285	46.8	62	68.3
FUNTUA	270	48.9	80	64.1
JARGABA RD. JUNCTION	-	49.1	91	59.1
MALUMFASHI	284	50.0	105	58.9
GORA	284	50.5	121	56.9
DAYI	282	50.1	130	54.2
MUSAWA RD. JUNCTION	273	51.0	144	55.7
KANO RD. JUNCTION (NEAR YASHI)	291	45.5	172	50.1
KANKIYA RD. JUNCTION	280	49.8	191	46.9
BINDAWA " " (NEAR CHERANCHI)	274	50.6	202	-
RIMI RD. JUNCTION	260	47.7	222	40.5
KATSINA	252	46.5	240	39.4
BATAGARAWA RD. JUNCTION	-	48.6	231	40.4
KURFI	-	52.5	203	46.0
DUTSIN-MA	245	51.5	179	49.2
YANTUMAKI	-	52.9	150	52.6
KANKARA	256	49.6	123	55.3

Appendix 4.1 E_3 (Contd.)

DATE: 29/8/81	RADIO NIGER MINNA METUNBI - 702 kHz		KANO STATE RADIO JOGANNA - 728 kHz	
LOCATIONS	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
SHIKA	207	40.4	158	55.0
GIWA RD. JUNCTION	206	32.9	164	53.3
MASKA	210	43.3	169	53.1
FUNTUA	222	35.3	165	54.0
JARGABA RD. JUNCTION	-	39.1	143	58.1
MALUMFASHI	266	38.1	126	60.2
GORA	281	37.5	116	64.7
DAYI	289	36.1	113	65.1
MUSAWA RD. JUNCTION	305	35.6	108	64.2
KANO RD. JUNCTION (NEAR YASHI)	-	30.9	96	62.5
KANKIYA RD. JUNCTION	351	32.7	112	59.3
BINDAWA " " (NEAR CHERANCHI)	362	25.8	128	57.4
RIMI RD. JUNCTION	375	24.9	144	54.2
KATSINA	389	24.7	161	50.0
BATAGARAWA RD. JUNCTION	-	25.9	156	50.4
KURFI	-	30.9	151	55.8
DUTSIN-MA	330	33.1	141	60.0
YANTUMAKI	303	35.3	137	60.3
KANKARA	271	37.6	144	60.0

Appendix 4.1 E_4

DATE: 29/8/81 LOCATIONS	FRCN KADUNA JAJI - 593 kHz		KANO STATE RADIO JOGANNA - 726 kHz	
	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)	DISTANCE (km)	NORMALISED FIELD STRENGTH (dB)
SHIKA	42	63.7	158	38.0
GIWA RD. JUNCTION	49	62.1	164	36.3
MASKA	62	58.3	169	36.1
FUNTUA	80	54.1	165	37.0
JARGABA	91	49.1	143	41.1
MALUMFASHI	105	48.9	126	43.2
GORA	121	46.9	116	47.7
DAYI	130	44.2	113	48.1
MUSAWA RD. JUNCTION	144	45.7	108	47.2
KANO " " (NEAR YASHI)	172	40.1	96	45.5
KANKIYA " "	191	36.9	112	42.3
BINDAWA " " (NEAR CHERANCHI)	202	-	128	40.4
RIMI RD. JUNCTION	222	30.5	144	37.2
KATSINA	240	29.4	161	33.0
BATAGARAWA RD. JUNCTION	231	30.4	156	33.4
KURFI	203	36.0	151	38.8
DUTSIN-MA	179	39.2	141	43.0
YANTUMAKI	150	42.6	137	43.3
KANKARA	123	45.3	144	43.0

Appendix 4.1 F_1

DATE: 9/6/81	FRCN KADUNA JAJI - 593 kHz		RIMA RADIO SOKOTO SHUNI - 557 kHz	
LOCATIONS	DISTANCE (km)	FIELD STRENGTH (dB)	DISTANCE (km)	FIELD STRENGTH (dB)
MAIRUWA RD. JUNCTION	91	60.4	-	49.8
SHEMI " "	105	59.6	260	52.7
YANKARA	117	56.7	234	53.3
CHAFE	142	46.8	207	55.6
KWATARKWASHI	164	49.6	188	57.8
GUSAU	177	48.6	171	61.4
BUNGUDU RD. JUNCTION	192	46.8	156	64.1
MARU	209	42.9	137	64.8
MAIINCHI	218	38.7	120	67.8
TALATA MAFARA	252	39.6	93	74.6
BAKURA RD. JUNCTION	269	34.6	73	74.6
TURETA " "	293	30.1	47	86.0
DANGE	326	29.5	13	100.4

Appendix 4.1 F_1 (Continued)

DATE: 9/6/81	KANO STATE RADIO JOGANNA - 728 kHz	
LOCATIONS	Distance (km)	Field Strength (dB)
MAIRUWA RD. JUNCTION	171	55.5
SHEMI " "	175	56.1
YANKARA	182	53.8
CHAFE	197	50.0
KWATARKWASHI	208	49.5
GUSAU	226	46.9
BUNGUDU RD. JUNCTION	236	48.0
MARU	256	45.3
MAIINCHI	270	40.2
TALATA MAFARA	295	40.0
BAKURA RD. JUNCTION	316	38.7
TURETA " "	342	31.1
DANGE	374	33.3

Appendix 4.1 F_2

DATE: 9/6/81	FROM KADUNA JAJI - 593 kHz		RIMA RADIO SOKOTO SHUNI - 557 kHz	
LOCATIONS	DISTANCE (km)	NORMALIZED FIELD STRENGTH (dB)	DISTANCE (km)	NORMALIZED FIELD STRENGTH (dB)
MAIRUWA RD. JUNCTION	91	50.4	-	32.8
SHEMI " "	105	49.6	260	35.7
YANKARA " "	117	46.7	234	36.3
CHAFE	142	-	207	38.6
KWATARKWASHI	164	39.6	188	40.8
GUSAU	177	38.6	171	44.4
BUNGUDU RD. JUNCTION	192	36.8	156	47.1
MARU	209	32.9	137	47.8
MAIINCHI	218	28.7	120	50.8
TALATA MAFARA	252	29.6	93	57.6
BAKURA RD. JUNCTION	269	24.6	73	57.6
TURETA " "	293	20.1	47	69.0
DANGE	326	19.5	13	83.4

Appendix 4.1 F_3

DATE: 9/1/82	RIMA RADIO SOKOTO SHUNI - 558 kHz		FRCN KADUNA JAJI - 593 kHz	
LOCATIONS	Distance (km)	Field Strength (dB)	Distance (km)	Field Strength (dB)
SHIKA	311	42.3	42	74.2
GIWA RD. JUNCTION	295	45.3	49	72.9
FUNTUA/BAKORI RD. JUNCTION	270	50.4	80	61.7
SHEMI RD. JUNCTION	260	52.7	105	59.2
CHAFE	207	56.2	142	51.1
KWATARKWASHI	188	58.5	164	50.9
GUSAU	171	61.8	177	49.2
BUNGUDU RD. JUNCTION	156	65.3	192	48.0
MARU	137	66.0	209	44.1
MAIINCHI RD. JUNCTION	120	69.1	218	40.0
TALATA MAFARA	93	75.0	252	38.1
BAKURA RD. JUNCTION	73	75.3	269	36.1
TURETA RD. JUNCTION	47	86.4	293	30.4
DANGE	13	101.1	326	31.4
SHUNI	-	-	340	29.2
SOKOTO	10	96.3	352	27.0

Appendix 4.1 F_3 (Continued)

DATE: 9/1/82	RADIO NIGER, MINNA METUNBI - 702 kHz		KANO STATE RADIO JOGANNA - 729 kHz	
LOCATIONS	DIST. (km)	FIELD STRENGTH (dB)	DIST. (km)	FIELD STRENGTH (dB)
SHIKA	207	40.0	158	56.4
GIWA RD. JUNCTION	206	42.1	164	55.6
FUNTUA/BAKORI JUNCTION	222	42.3	165	59.1
SHEMI RD. JUNCTION	-	40.2	175	55.6
CHAFE	262	38.5	197	50.1
KWATARKWASHI	280	37.1	208	49.5
GUSAU	283	38.7	226	45.8
BUNGUDU RD. JUNCTION	293	39.1	236	48.6
MARU	302	38.1	256	46.0
MAIENCHI RD. JUNCTION	307	35.0	270	41.2
TALATA MAFARA	331	32.5	295	38.3
BAKURA RD. JUNCTION	336	31.1	316	38.1
TURETA RD. JUNCTION	352	28.9	342	31.4
DANGE	379	21.6	374	33.1
SHUNI	391	24.1	382	33.1
SOKOTO	405	22.9	387	30.1

Appendix 4.1 F_4

DATE: 9/1/82	RIMA RADIO SOKOTO SHUNI - 558 kHz		FRCN KADUNA JAJI - 593 kHz	
LOCATIONS	Distance (km)	Normalised Field Strength (dB)	Distance (km)	Normalised Field Strength (dB)
SHIKA	311	25.3	42	64.2
GIWA RD. JUNCTION	295	28.3	49	62.9
FUNTUA/BAKORI RD. JUNCTION	270	33.4	80	51.7
SHEMI RD. JUNCTION	260	35.7	105	49.2
CHAFE	207	39.2	142	41.1
KWATARKWASHI	188	41.5	164	40.9
GUSAU	171	44.8	177	39.2
BUNGUDU RD. JUNCTION	156	48.3	192	38.0
MARU	137	49.0	209	34.1
MAIINCHI RD. JUNCTION	120	52.1	218	30.0
TALATA MAFARA	93	58.0	252	28.1
BAKURA RD. JUNCTION	73	58.3	269	26.1
TURETA RD. JUNCTION	47	69.4	293	20.4

APPENDIX 4.2

COMPUTER CALCOMP PROGRAMME FOR PLOTT
NORMALIZED FIELD STRENGTH ON THE TH
PROPAGATION CURVES.

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INNESOTA FORTRAN COMPILER (VERSION 5.0 - 77/03/24) ON THE CY72
     MNF,B=LGO,P=65000.
     C      THE PROGRAMME WAS PUNCHED ON CARDS
0B           PROGRAM GR(INPUT,OUTPUT,TAPE27,TAPE5=INPUT,TAPE6=OUT
7B           DIMENSION X(205),Y(205)
1B           CALL PLOTS(0,0,27)
5B           CALL FACTOR(0.75)
7B           CALL AXIS(0.,0.,13HDISTANCE (KM),-13,25.,0.,0.,8.)
1B           CALL AXIS(0.,0.,49HELECTRIC FIELD INTENSITY (DB REL.
            1M),+49,26.,90.,22.,3.)
3B           Y(197)=22.
3B           Y(198)=3.
5B           X(197)=0.
6B           X(198)=8.
7B           READ(5,100)F
     C      THE TRANSMITTER FREQUENCY(F) IS IN MHZ
4B      100  FORMAT(F5.3)
4B           WRITE(6,102)F
0B      102  FORMAT(5X,F5.3)
5B           WL=300./F
     C      WL IS WAVELENGTH IN METRES
1B           DO 35 N=1,20
     C      N IS THE GROUND CONDUCTIVITY IN MMHO/M
3B           R=(18.*FLOAT(N))/F
5B           PERM=4.
     C      PERM IS THE RELATIVE PERMITTIVITY OF THE GROUND
7B           S1=(PERM-1.)/R
1B           S2=PERM/R
2B           B1=ATAN(S1)
6B           B2=ATAN(S2)
7B           WRITE(6,103)S1,B1,S2,B2
0B      103  FORMAT(3X,4(E16.6,8X))
0B           DO 34 I=1,196
1B           X(I)=5.+FLOAT(I-1)
     C      X(I) IS THE DISTANCE FROM THE TRANSMITTER IN KM
0B           DX=X(I)*10**3
     C      D(X) IS THE DISTANCE FROM THE TRANSMITTER IN METRES
4B           PI=3.1415927
6B           P=(PI*DX*COS(B2)*COS(B2))/(R*WL*COS(B1))
     C      P IS A NUMERICAL DISTANCE
2B           B=2.*B2-B1
     C      B IS THE PHASE CONSTANT
4B           A1=(2.0+0.3*P)/(2.0+P+0.5*P*P)
3B           EXP=2.7182818
3B           A2=SQRT(P/2.0)*SIN(B)
4B           PH6=0.625*P
4B           TXP=EXP**PH6
5B           A=A1*A2/TXP
     C      A IS THE FACTOR THAT CONSIDERS THE GROUND LOSSES
2B           PW=1.0
     C      PW IS THE EFFECTIVE RADIATED POWER IN KILOWATT
3B           E1=150.0*SQRT(PW)
5B           E=2.*E1*(A/DX)*1E**3
     C      E IS THE ELECTRIC FIELD IN MMV/M
2B           Y(I)=20.*ALOG10(E)+5.
     C      Y(I) IS THE ELECTRIC FIELD IN DB(REL. 1 MICRO-VOLT/
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```
      34 CONTINUE
         DO 75 L=1,2
         CALL LINE(X,Y,195,1,0,2)
      75 CONTINUE
      35 CONTINUE
C        SUB-PROGRAM FOR DRAWING THE VERTICAL LINES
         CALL PLOT(0.,0.,3)
         Y(28)=22.
         Y(29)=3.
         X(28)=0.
         X(29)=8.
         DO 2  N=1,25
         XX=8.+FLOAT((N-1)*8)
         DO 1  J=1,27
         X(J)=XX
         Y(J)=22.+FLOAT((J-1)*3)
      10 CONTINUE
         CALL LINE(X,Y,27,1,0,2)
      20 CONTINUE
C        SUB-PROGRAM FOR DRAWING THE HORIZONTAL LINES
         CALL PLOT(0.,0.,3)
         Y(27)=22.
         Y(28)=3.
         X(27)=0.
         X(28)=8.
         DO 6  N=1,26
         YY=25.+FLOAT((N-1)*3)


         DO 65 J=1,26
         Y(J)=YY
         X(J)=FLOAT((J-1)*8)
      65 CONTINUE
         CALL LINE(X,Y,26,1,0,2)
      60 CONTINUE
C        SUB-PROGRAM FOR PLOTTING THE POINTS BEGINS
         CALL PLOT(0.,0.,3)
         Y(8)=22.
         Y(9)=3.
         X(8)=0.
         X(9)=8.
         READ(5,90) (X(L),L=1,7)
      90 FORMAT(7F5.1)
         READ(5,95) (Y(L),L=1,7)
      95 FORMAT(7F4.1)
         WRITE(6,98) (X(L),Y(L),L=1,7)
      98 FORMAT(3X,F5.1,6X,F4.1)
         CALL LINE(X,Y,7,1,-1,4)
         CALL PLOT(0.,0.,3)
         Y(7)=22.
         Y(8)=3.
         X(7)=0.
         X(8)=8.
         READ(5,80) (X(L),L=1,6)
      80 FORMAT(6F5.1)
         READ(5,85) (Y(L),L=1,6)
      85 FORMAT(6F4.1)
         WRITE(6,87) (X(L),Y(L),L=1,6)
      87 FORMAT(3X,F5.1,6X,F4.1)
         CALL LINE(X,Y,6,1,-1,2)
         CALL PLOT(0.,0.,99)
         WRITE(6,101)
     101 FORMAT(3X,*TEST PLOT COMPLETED*)
         STOP
         END
```