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Honorary Editor: A. W. LINEKER, B.Sc.
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Volume 45 APRIL 1954 Part 4

PROCEEDINGS AT THE FOUR HUNDRED AND FORTY-THIRD GENERAL MEETING

Held at Kelvin House, corner Marshall and Hollard Streets, Johannesburg

Thursday, 22nd April 1954

PROFESSOR G. R. BOZZOLI (Vice-President) was in the Chair and declared the meeting opened at 8.5 p.m.

There were present 30 members and visitors and the Secretary.

Before opening the meeting the Chairman advised members that news had been received of the President to the effect that he was progressing favourably. It was hoped that he would soon be back with them.

MINUTES

The minutes of the monthly general meeting held on the 25th March 1954, were taken as read and confirmed.

MEMBERSHIP

THE CHAIRMAN announced that in terms of By-Law 5.2.4, the Council had elected the undermentioned candidates to membership of the Institute in the following grades :—

Member : WILLIAM ERIC PHILLIPS.

Associate Members : DEREK SPENCER FLEISCHER, WILFRED HUBERT GOLD, ROY GORDON HULLEY, FREDERICK WILHELM MEERKOTTER, JUGMAR OFVERHOLM, CHARLES BRUCE READ, CHRISTIAAN ABRAHAM VISSER, EDWARD REARDON WELCH.

Graduates : WILLIAM DAVID EVANS, LESLIE TUCK, RYNO VERSTER.

Associates : SELWYN JAMES BARTHOLOMEW, STANLEY VICTOR WILLETT CLARKE, FREDERICK JACOBUS COETZEE.

Transfer from Associate Member to Member : RALPH SWALLOW DUNSTAN.

Transfer from Graduate to Associate Member : WILFRED SPENCER CAREY, ROLAND FREDERICK MUNYARD, PETER BENTLEY POWER.

Transfer from Student to Graduate : DAVID MURRAY, ROY WILLIAM PATRICK, PHILLIPS REGINALD ROSEN.

Transfer from Student to Associate : ISAK DAWID DU PLESSIS, BERNARD THEODORE OPPERMAN.

GENERAL BUSINESS

THE CHAIRMAN announced that a joint meeting under the auspices of the University of the Witwatersrand and The Chemical, Metallurgical and Mining Society of South Africa would be held in the Great Hall, University, Milner Park, Johannesburg, on Wednesday, 28th April 1954, at 8 p.m. when Mr C. S. McLean would deliver an address entitled 'The uranium industry of South Africa.' A cordial invitation had been extended to members of the Institute to attend that meeting.

PAPER AND DISCUSSION

The paper entitled 'A survey of ground wave propagation conditions in South Africa,' was presented by R. W. Vice.

The Chairman proposed a vote of thanks to the author for his paper and T. G. E. Cockbain (Associate), G. Damant and F. J. Hewitt (Associate Member) contributed to the discussion. In the unavoidable absence of Mr Damant his contribution was read by D. Q. Mayne (Graduate).

ITEM OF PRACTICAL INTEREST

An item of practical interest entitled 'Improved ventilation on a winder motor,' was presented by J. K. Gillett (Member).

The President declared the meeting closed at 9.25 p.m.

Institute Notes

Cape Western Local Centre

Members of the Institute visiting Cape Town are cordially invited to attend general meetings of the Cape Western Local Centre which are held in Demonstration Theatre, Electricity House, Strand Street, Cape Town, on the second Thursday of each month.

A general meeting of the Cape Western Local Centre was held in the Demonstration Theatre, Electricity House, Strand Street, Cape Town, on Thursday, 22nd April, 1954.

Mr C. G. Downie (Chairman of the Centre) was in the Chair and declared the meeting opened at 8.12 p.m. Eighty-five members and visitors were present.

An address on the 'Electricity supply in Great Britain,' dealing with the development of the Electricity Supply industry in the United Kingdom since its nationalization in 1947, was presented by Sir John Hacking, a Past President of the Institution of Electrical Engineers, London, who, until he retired recently, was Deputy Chairman (Operations) of the British Electricity Authority'

Mr Joseph White (Honorary Member, Past President) proposed the vote of thanks to Sir John Hacking, which was seconded by Mr C. N. Larkin (Vice-Chairman of the Centre).

The address was then open to discussion and the following contributed thereto :—The Chairman, Mr H. H. Jagger (Member) (Past Chairman), Dr H. D. Einhorn (Member) Messrs J. S. McHutchin, B. W. Kuttel (Graduate), J. M. Georgalia (Associate), S. T. Clifford Jones, J. C. Baillie (Associate Member), C. W. Everett, and S. S. Wolf (Associate). Sir John Hacking replied to a number of the questions raised by the contributors.

There being no further business, the Chairman declared the meeting closed at 10.30 p.m.

A SURVEY OF GROUND WAVE PROPAGATION CONDITIONS IN SOUTH AFRICA

By R. W. VICE,* B.Sc.(Eng.)

Paper received on 1st December 1953

SUMMARY

The theory of ground wave propagation and the determination of effective ground conductivity by field strength measurements are discussed. The field strength survey of South Africa, at frequencies below 1 mc/s, is described. The results are presented in the form of a map showing the effective ground conductivity at 500 kc/s, and a curve showing the average relation between ground conductivity and frequency.

CONTENTS

1. INTRODUCTION

Ground wave propagation at frequencies below 1 mc/s is dependent largely on the conductivity, and, to a lesser extent, on the dielectric constant of the ground. A knowledge of the ground conductivity makes it possible to predict the field strengths of any transmitter of known power. It is therefore of great aid in planning any system employing ground wave propagation.

It was recommended in 1948 by the Telecommunications Advisory Committee that the Telecommunications Research Laboratory should contact a ground conductivity survey of the Union of South Africa and South West Africa. Ground conductivity was to be measured by its effect on ground wave propagation.

Work on the design and construction of the necessary equipment was begun early in 1949. The first field strength measurements were taken on the occasion of the South African Decca trials, during the first half of 1950. The survey was then extended over the Union and South West Africa, and the field work was completed towards the end of 1952.

2. THEORY OF GROUND WAVE PROPAGATION

2·1 *Definition of ground wave*

The ground wave is that portion of a radio wave which is affected by the presence of the ground and by refraction in the lower atmosphere. It excludes ionospheric waves.

2·2 *Factors influencing the ground wave*

Ground wave propagation is influenced by the following factors :—

- *i* The conductivity and dielectric constant of the ground
- *ii* The heights of the transmitting and receiving aerials
- *iii* Refraction in the lower atmosphere
- *iv* The polarization of the wave
- *v* The presence of irregularities such as mountains on the earth's surface.

2·3 *General expression for ground wave field strength*

When the transmitter and the receiver are sufficiently high above the surface of the earth, the field strength at a distance short enough for earth curvature to be neglected is simply the vertical sum of fields due to the direct and ground reflected waves. These two waves constitute the space wave. When the transmitting aerial is a vertical doublet this is given by

* Mr Vice is a Research Officer in the Telecommunications Research Laboratory of the Council of Scientific and Industrial Research.

$$E=E_o/d\left[\cos^3\psi_1 e^{\frac{j2\pi r_1}{\lambda}}+R\cos^3\psi_2 e^{\frac{j2\pi r_2}{\lambda}}\right] \quad ...1$$

where j is $\sqrt{(-1)}$, R the plane wave reflection coefficient of the ground, and E_o the free space field strength at unit distance on the equatorial plane of the doublet. E is the received field in the same units as E_o. The other quantities are as shown in Fig. 1.

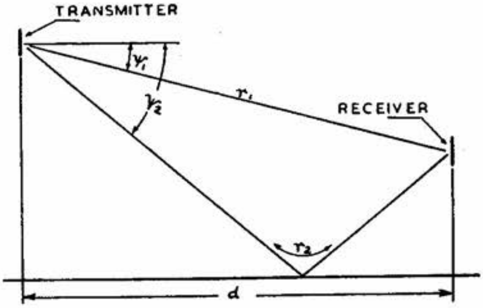

Fig. 1—Diagram illustrating quantities appearing in equation 1

At smaller heights diffraction effects due to the presence of the earth must be taken into account. The resulting expression for the field strength of a vertically polarized wave assumes a convenient form if a 'surface wave' is postulated, such that the field is given by the vertical sum of the fields due to the surface wave, the direct wave, and the ground reflected wave, the latter two components being given by *1*.

The expression now becomes

$$E=E_o/d\left[\cos^3\psi_1 e^{\frac{j2\pi r_1}{\lambda}}+R\cos^3\psi_2 e^{\frac{j2\pi r_2}{\lambda}}+(1-R)F_1\right] \quad ...\ 2$$

where F_1 is a complex function of the ground constants, the frequency, the aerial heights, and the distance. The surface wave is represented by the term $\frac{E_o}{d}(1-R)F_1$.

In the practical case of finitely conducting ground, $R\to -1$ at small angles of incidence, and the space wave becomes negligible. The surface wave accounts for the total field, which becomes

$$E=2E_o/d\times F_1 \quad ...\quad ...\quad ...\ 3$$

For a sufficiently short distance or high conductivity, $F_1\to 1$, and the field is given by $2E_o/d$, the 'inverse distance' field.

The angle of incidence at which the space wave becomes negligible decreases as the wavelength or the conductivity increases, becoming zero for infinitely high conductivity. In this case $R=1$, and the surface wave is zero. The space wave now accounts for the total field which, for small aerial heights, becomes $2E_o/d$.

For sufficiently small angles of incidence $F_1=1$ when the transition from $R=-1$ to $R=1$ occurs. Hence in this transition region *1* becomes

$$E=E_o/d\ (1+R+1-R)=2E_o/d$$

Thus, when the conductivity is sufficiently high for the field strength to assume the value $2E_o/d$, any further increase of conductivity up to an infinitely large value leaves the field strength unaltered, even though there is a complete transition from the surface wave to the space wave condition.

At distances too large for the earth curvature to be neglected the above analysis no longer applies. The ground wave is able to follow the contour of the earth, partly by refraction and partly by diffraction. Refraction is taken into account by assuming the effective radius of the earth to be increased by a factor k, which depends on the variation of the dielectric constant of the atmosphere with height. Its value is not constant, but an average value of 4/3 is assumed. For small transmitter and receiver heights the received field can again be expressed as a fraction of the inverse distance field, that is,

$$E=2E_o/d\times F_2 \quad ...\quad ...\quad ...\ 4$$

F_2 is a function of the ground constants, frequency, distance, and of the factor k mentioned above. The magnitude of E_o depends on the type of transmitting aerial and on the radiated power. For a short vertical aerial $E_o=93\sqrt{P}$ millivolts per metre at one mile, where P is the radiated power expressed in kilowatts.

2·4 *Ground wave propagation curves*

The factors F_1 and F_2 can be evaluated by a semi-graphical method presented by Norton.[1] Theoretical propagation curves can then be obtained, using *3* and *4*. A set of theoretical propagation curves derived by Norton's method is given in Figs. 2-13. These curves apply to propagation of vertically polarized waves over a smooth, homogeneous earth, both transmitter and receiver being near to the surface of the earth. An average value for the dielectric constant of the ground has been assumed, propagation at the frequencies to which the curves apply being largely independent of dielectric constant.

In Fig. 2 field strength is plotted against distance for different values of ground conductivity, at a frequency of 500 kc/s. The inverse distance field has been arbitrarily chosen as 10 mv/metre at one mile.

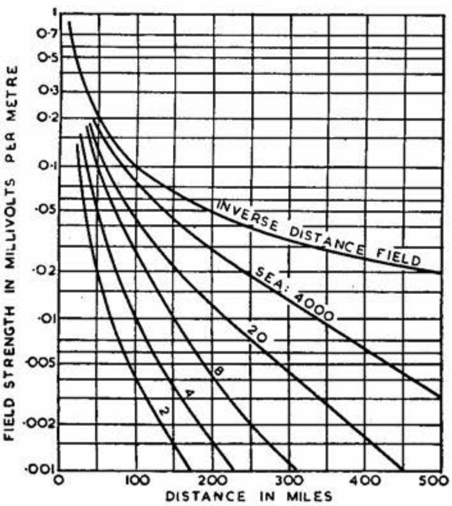

Fig. 2—Ground wave propagation at 500 kc/s, for the case where the field strength at 1 mile is 10 mV/m. As in subsequent figures the numbers on the curves denote ground conductivities expressed in e.m.u's = 10^{-14}

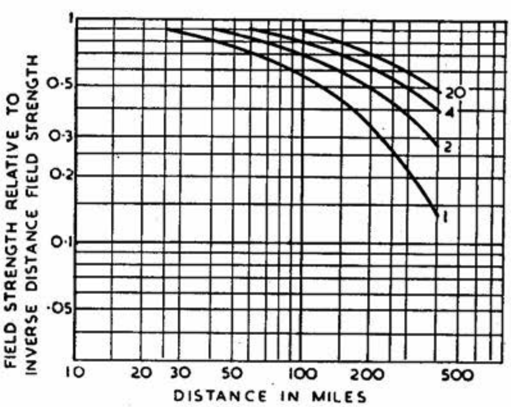

Fig. 3—Ground wave propagation at 100 kc/s

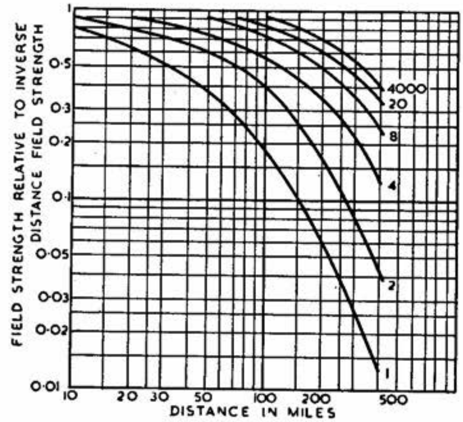

Fig. 4—Ground wave propagati9n at 200 kc/s

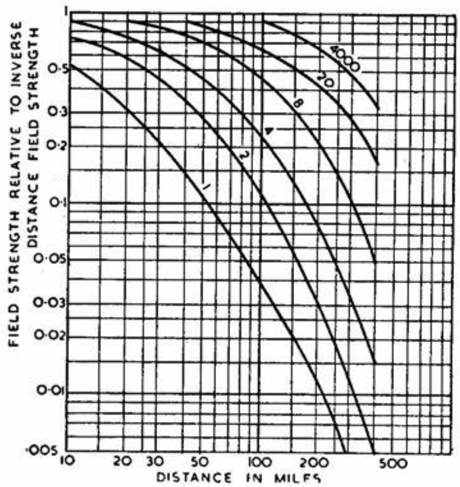

Fig. 5—Ground wave propagation at 350 kc/s

Propagation over sea is practically the same as over ground of infinitely high conductivity, hence the sea curve indicates the loss due to earth curvature. The curves for propagation over finitely conducting ground illustrate the effect of ground conductivity on the range of a transmitter and on the field strength at a given range.

In Figs. 3-7 are shown propagation curves for different frequencies between 100 kc/s and 1 mc/s. For convenience the ordinates of these curves represent the ratio of the actual field to the inverse distance field, $2E_o/d$, at each distance. To obtain the absolute value of field strength at a distance d from the transmitter the value indicated by the appropriate curve is multiplied by $2E_o/d$.

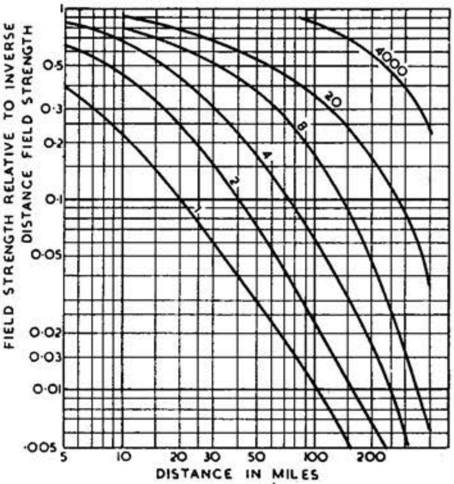

Fig. 6—Ground wave propagation at 600 kc/s

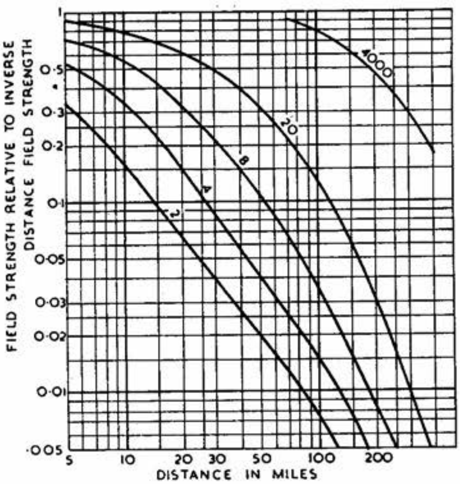

Fig. 7—Ground wave propagation at 1 000 kc/s

Each of the Figs. 8-13 shows a family of curves applying to a particular range from the transmitter. Field strength relative to the inverse distance field is plotted against frequency, for different values of ground conductivity. With the aid of these curves propagation curves for any frequency between 100 kc/s and 1 mc/s can be drawn.

The dependence of ground wave propagation on the ground constants varies according to conditions of frequency, range, and ground constants. At the 'long wave limit,' i.e. at sufficiently low frequency, high conductivity, or short range, the field strength becomes independent of the ground constants. The same effect occurs at the short wave limit. Under intermediate conditions field strength is very roughly proportional to ground conductivity. For frequencies between 100 kc/s and 1 mc/s average conditions approach the long wave limit rather than the short wave limit, and propagation curves for all values of conductivity approach the inverse distance curve at sufficiently short ranges. Thus the factor $2E_o/d$ can be determined by field strength measurements at short ranges.

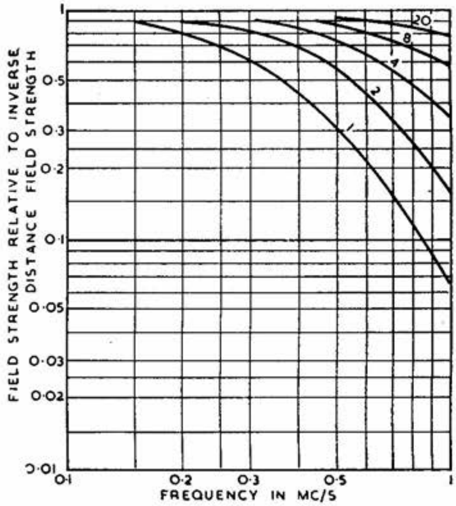

Fig. 8—Relative ground wave field strength at a range of 10 miles from the transmitter

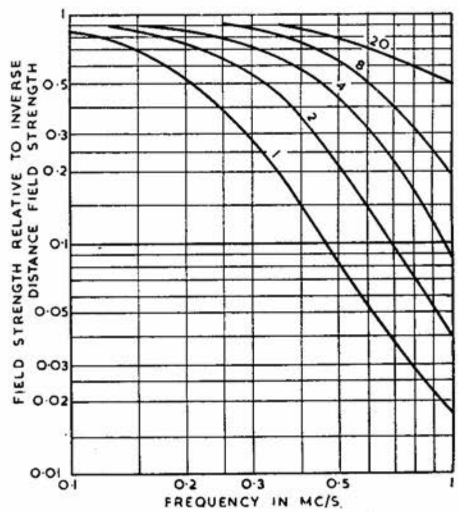

Fig. 9—Relative ground wave field strength at a rang of 30 miles from the transmitter

2·5 *Propagation over inhomogeneous ground*

The propagation curves given in Figs. 2-13 apply only to the case where ground constants are uniform over the whole transmission path, or where deviations from the mean value occur only over very short sections of the path, the mean value itself being uniform over the whole transmission path. When, however, the transmission path consists of several large sections of different mean conductivities, the type of propagation occurring over each section must be considered separately.

The analysis of propagation over inhomogeneous ground is very complex, and the problem has not yet been completely solved. A purely empirical solution has been suggested by Eckersley.[2] According to this theory, the curve applying to each section of the transmission path is characteristic of the ground constants of that

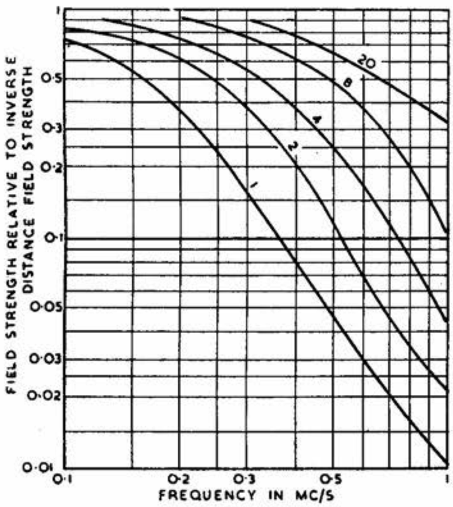

Fig. 10—Relative ground wave field strength at a range of 50 miles from the transmitter

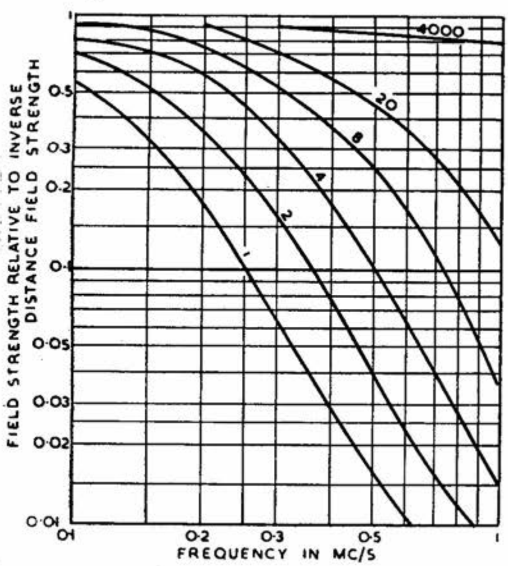

Fig. 11—Relative ground wave field strength at a range of 100 miles from the transmitter

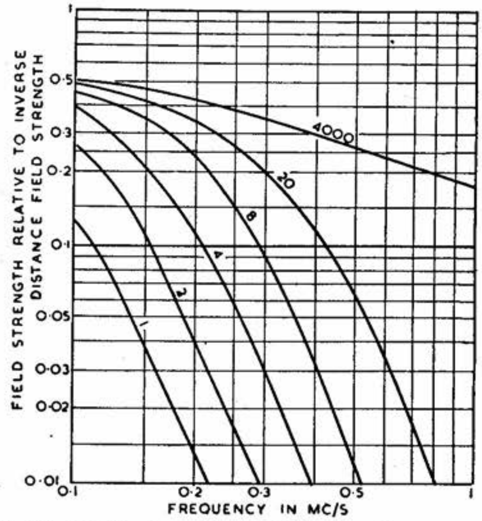

Fig. 12—Relative ground wave field strength at a range of 200 miles from the transmitter

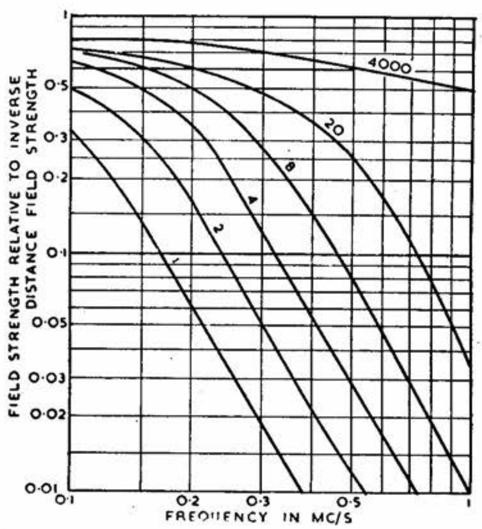

Fig. 13—Relative ground wave field strength at a range of 400 miles from the transmitter

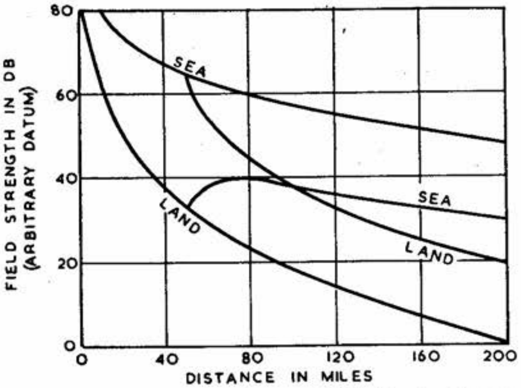

Fig. 14—Curves, based on Millington's theory, illustrating propagation at 1 mc/s over land-sea and sea-land boundaries

section alone, and is simply the corresponding section of the appropriate propagation curve for homogeneous ground, the absolute magnitude of each portion of the curve being adjusted to fit the preceding portion with no discontinuity at the boundaries. A drawback to this theory is that it does not satisfy the Reciprocity Law, which implies that the received field strength remains unchanged when the positions of the transmitter and receiver are interchanged.

Millington[3] has suggested that any empirical solution of this problem should satisfy these conditions, viz :—

i The Reciprocity Law must be satisfied.

ii If at a certain distance from the transmitter there is a boundary at which the wave crosses from one type of ground to another, then at a sufficient distance beyond the boundary the propagation must become characteristic of the ground constants of the new section, both as regards attenuation with distance and the height gain relation near the ground.

iii At the boundary some kind of disturbance must be set up to account for the transition of the propagation from one characteristic type to another, with the result that the propagation immediately beyond the boundary will not necessarily be characteristic of the ground constants of the new section.

Millington's empirical solution, which is designed to satisfy these requirements, consists in taking the geometric mean of the two values of field strength obtained when Eckersley's solution is applied to propagation in both directions along the transmission path. Millington's solution is formally stated as follows :—

Assume that for smooth homogeneous ground having ground constants denoted by n, the field strength at a distance d_n from a transmitter is $e_n(d_n)$. Then, for a transmission path of length d made up of n sections of lengths $d_1, d_2 \ldots\ldots\ldots d_n$, the field strength at a distance d from the transmitter is given by the geometric mean of the two values

$$e_1(d_1)\frac{e_2(d_1+d_2)}{e_2(d_1)}\;\frac{e_3(d_1+d_2+d_3)}{e_3(d_1+d_2)}\;-\;-\;-\;\frac{e_n(d)}{e_n(d_1+d_2+\ldots\ldots+d_{n-1})}$$

and

$$e_n(d_n)\frac{e_{n-1}(d_n+d_{n-1})}{e_{n-1}(d_n)}\;-\;-\;-\;\frac{e_1(d)}{e_1(d_n+d_{n-1}+\ldots\ldots+d_2)}$$

The above theory has several interesting implications. When a wave crosses from a section of low conductivity to one of very high conductivity, there may be a recovery of field strength immediately beyond the boundary, after which the propagation becomes characteristic of the new section.

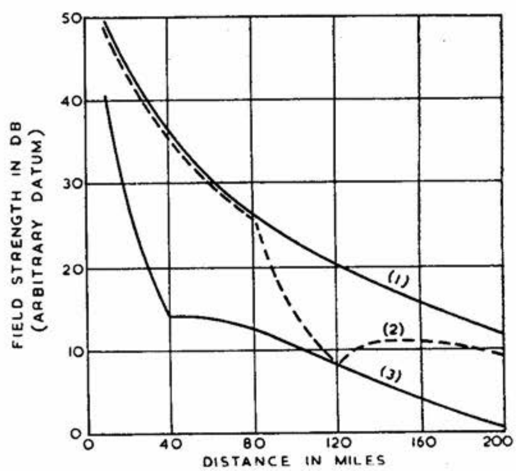

Fig. 15—Curves, based on Millington's theory, illustrating propagation at 500 kc/s over inhomogeneous ground

Curve 1 : Uniformly highly conducting ground
Curve 2 : Section of low conductivity between 80 and 120 miles
Curve 3 : Section of low conductivity between 0 and 40 miles

Fig. 14 illustrates typical theoretical propagation curves, based on Millington's theory, for transmission from sea to land and vice versa, at a frequency of 1 mc/s.

An interesting point is that the received field strength is higher for a transmission path consisting of 50 miles of sea and 50 miles of land, than for 50 miles of land only.

The relative importance of different sections of a transmission path is demonstrated by Fig. 15, in which the composite curves have been constructed by Millington's method.

Curve 1 is a propagation curve for transmission over 200 miles of ground of uniformly high conductivity. Curve 2 applies to a transmission path which includes centrally a 40 mile section of low conductivity, the remainder being the same as in the first case. These two curves show that the effect of the section of bad conductivity extends for only a short distance beyond that section, and the field strength at the end of the transmission path is not greatly reduced. Curve 3 represents the case where the 40 mile section of bad conductivity is adjacent to the transmitter. Here the effect of the initial bad conductivity is a marked reduction of field strength along the whole transmission path. It appears that transmission between two points is to a large extent dependent on the ground constants near the transmitter and the receiver, and to a lesser extent to the ground constants in the transmission path remote from the transmitter and receiver.

There is experimental evidence confirming that there is a recovery in field strength where a wave crosses from ground of low conductivity to ground of medium conductivity.[3] Measurements have been made showing that in the case of sea-land transmission the field strength decreases very rapidly over the first few miles of land.[4] Unfortunately the above experiments provide no quantitative confirmation of Millington's theory, as the ground constants of the various sections were not accurately known. Millington, however, quotes one controlled experiment in which a field strength recovery of 12 db, predicted by his theory, was confirmed by measurement.[3]

2·6 *Diffraction losses due to uneven ground*

Ground wave propagation over uneven ground is subject to diffraction losses as

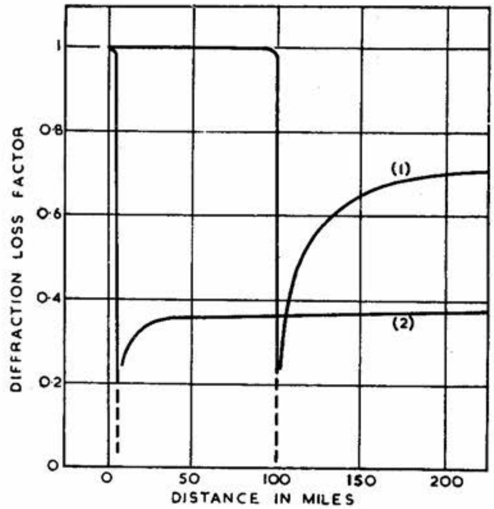

Fig. 16—Diffraction losses due to a 6 000 ft mountain range crossing the transmission path (1) 100 miles, and (2) 5 miles from a 500 kc/s transmitter

well as losses due to finite ground conductivity. At frequencies below 1 mc/s diffraction losses are negligible except in the case of propagation over mountains. The diffraction loss is large when the frequency is high, the height of the mountain is great, and when the transmitter or receiver is close to the mountain. Diffraction losses can be calculated, but many simplifying assumptions have to be made, and the results are only approximate. Methods of calculation, in the case of one or two mountain ranges crossing the transmission path at right angles, are given in the Appendix.

The effect of a mountain range crossing an otherwise smooth transmission path is similar to the effect, discussed in Section 2.5, of a section of low conductivity in a transmission path which is otherwise of of high ground conductivity. The field strength drops to a very low value immediately beyond the mountain. There is then a partial recovery of field strength, after which the propagation becomes characteristic of the ground constants. When the transmitter is far from the mountain range the recovery is very nearly complete, and the effect of the mountain extends for a comparatively short distance. When, however, the transmitter is close to the mountains, the recovery is by no means complete, and field strengths at all points beyond the mountain are reduced.

The above effect is illustrated by Fig. 16, which applies to transmission at 500 kc/s.

Curve 1 gives the diffraction loss factor due to a 6 000 foot high range of mountains crossing the transmission path at right angles, 100 miles from the transmitter. When the mountain range is 5 miles from the transmitter, the diffraction loss factor is given by curve 2. (The diffraction loss factor is here defined as the ratio of the field strength of a wave propagated over uneven ground, to the field strength which would exist in the case of smooth ground, all other factors being equal.)

When more than one mountain range crosses the transmission path, the diffraction loss factor at any one point beyond the mountains is approximately the product of the diffraction loss factors associated with each of the mountain ranges considered separately, provided that the ranges are not too close together. A further condition is that the ground between the ranges is at zero height relative to the straight line from the transmitter to the receiver. It must, however, be noted that the above theory is an approximation, and, further, that the errors due to approximations in the calculation of each separate diffraction loss factor are multiplied.

The effects of diffraction losses on the determination of ground conductivity by field strength measurements must be considered. In cases where propagation occurs over a large, uniformly mountainous area, in which the mountains do not form one or two definite ranges, the diffraction losses can be considered as part of the loss due to an effective ground conductivity lower than the true value. As the mountains are uniformly distributed over the area, the diffraction losses will be roughly the same for all transmission paths, and the use of the effective value of conductivity in field strength calculations will not give rise to large errors.

The above method is not valid when applied to diffraction losses not typical of the whole area. Such diffraction losses are those caused by a mountain range higher than the average, or by a mountain range in otherwise flat country. A further example is the loss due to a mountain which is particularly close to either the transmitter or the receiver. These losses do not occur for all transmission paths over the area concerned, and they must be evaluated and allowed for before the ground conductivity is determined.

2·7 *Effect of aerial height*

In general, as the height of the transmitter or receiver above the earths' surface is increased, the received field changes. The higher the frequency, the sooner this change occurs, and at low frequencies the field strength remains constant up to considerable heights. Under these conditions the received field is modified by height-gain factors associated with the transmitter and the receiver. The height-gain factor is a function of the ground constants, the height of the transmitter or receiver, and the frequency. Under certain limited conditions the height-gain factor can be obtained directly from Norton's graph.[1] Outside these limits the field strength must be evaluated from the general expression for ground wave field strength (Equation 2).

Beyond a certain distance from the transmitter the field strength of a vertically polarized wave shows an initial decrease with increase of height, reaching a minimum value not more than 3 db below the surface value, and thereafter increasing above the surface value. For ground of average conductivity the field strength is within 3 db of the surface value up to a height of approximately 140 000 feet at a frequency of 100 kc/s, 12 000 feet at 500 kc/s and 4 500 feet at 1 mc/s. Over ground of bad conductivity these heights are reduced.

In the case of propagation over inhomogeneous ground, when a wave crosses a boundary between sections having different ground constants, it may be assumed that the height-gain at a sufficient distance beyond the boundary is characteristic of the ground constants of the new section alone.

Similarly, when a wave crosses a mountain range, it is to be expected that a sufficient distance beyond the mountains the height-gain will be unaffected by the presence of the mountains. At shorter distances no generalizations are possible, and individual problems are best solved by application of the methods outlined in the Appendix.

2·8 *Ground conductivity*

Ground conductivity at low and medium frequencies is determined by conditions existing to a considerable depth below the surface. For homogeneous ground the current density decreases exponentially with depth, and for ground of high conductivity (20×10^{-14} e.m.u.) the depth at which the current density is 1/4 of the surface value is 52 feet at 100 kc/s, and 16 feet at 1 mc/s. For ground of low conductivity (2×10^{-14} e.m.u.) the corresponding depths are 170 feet and 60 feet. Thus, in general, ground conductivity effective to propagation at these frequencies depends on the properties both of the soil and of the underlying rock.

Resistivity values of rock, tabulated by C. F. Boyce,[5] show variations of as much as 50 to 1 for the same type of rock. Similar with variations in the resistivity of granite were obtained by Smith-Rose.[6] In addition, his measurements on granite and slate at frequencies up to 10 mc/s show a marked increase of conductivity with frequency. Between the frequencies of 100 kc/s and 1 mc/s the conductivity increased, on the average, by a factor of 4·5.

Soil conductivity is a function of the type of soil, the nature and amount of soluble material present, the temperature, and the moisture content. The latter, in turn, depends on the type of soil, the rainfall, and the magnitude of evaporation and transpiration losses.

Measurements by Rose-Smith[7] on soil samples show the effect of moisture content on soil conductivity to be large. For moisture contents of between 1 and 30 per cent a 2 to 1 increase of moisture content increased the conductivity of four soil samples at 1·2 mc/s by a factor ranging from 3 to 30. Measurements on a large number of soil samples from the same site, at frequencies from 100 kc/s to 10 mc/s, showed an increase of conductivity with frequency, particularly with low moisture content. For a moisture content of 3·6 per cent the conductivity increased by a factor of 3 from 100 kc/s to 1 mc/s, whereas for moisture contents above 10 per cent the conductivity was practically constant.

Smith-Rose[6] measured the temperature coefficient of conductivity of different types of soil, at a frequency of 1·2 mc/s. Between the temperatures of 5° and 30°C he obtained values between 2·1 and 2·3 per cent per degree C, referred to the value at 20°C. Higgs[8] obtained a value of 3 per cent per degree C at a frequency of 50 c/s. It is evident that ground conductivity effective to the propagation of radio waves depends on a large number of factors. Since many of these factors, and their effect on ground conductivity are known only within wide limits, the effective ground conductivity is best determined directly by propagation measurements.

2·9 *Variation in time of ground wave field strengths*

Some of the factors influencing ground wave propagation are not constant, and the possibility of ground wave field strengths varying in time must be considered.

Propagation over large distances is influenced by the factor k, the effective increase of the earth's radius due to refraction. It has an average value of 4/3, but is subject to hourly, daily and seasonal variations and can range from less than 1 up to an infinitely large value. Variation of k has comparatively little effect on propagation at low frequencies and at moderate ranges. As an example, for propagation at 300 kc/s a change in the value of k from 4/3 to an infinitely large value increases the field strength at a range of 200 miles by only 3 db.

Ground conductivity is a function of the temperature and moisture content of the ground, and these factors are possible sources of variation. The daily variation of ground temperature decreases rapidly with depth. Smith-Rose[6] quotes measurements which showed that a 20°C daily variation at the surface produced a variation of only 1·4°C at a depth of one foot. Consequently daily variations in ground wave field strength, due to temperature changes, may be neglected.

Ground temperature measurements, carried out over a period of years at 8 sites throughout South Africa,[9] show that the annual variation of ground temperature decreases exponentially with depth. At depths of 1, 4, and 10 feet, mean annual temperature ranges of up to 16, 11 and 5·5°C respectively were obtained.

For homogeneous ground of conductivity 20×10^{-14} e.m.u., the top 4 feet of ground carries 10 per cent of the current at 100 kc/s, 21 per cent at 500 kc/s, and 30 per cent at 1 mc/s. For ground of conductivity 2×10^{-14} e.m.u. these figures become 3½, 7 and 9 per cent respectively. Assuming a temperature coefficient of conductivity of 2·5 per cent per degree C, it is expected that the annual variation of ground wave field strength due to variation of temperature will not exceed 10 per cent above or below the mean value, even at frequencies near 1 mc/s, and for ground of high conductivity.

With regard to the moisture content of soils in South Africa, very little data are available. M. J. Marais has carried out some moisture content measurements at the Agricultural Research Institute, Pretoria.[10] In a plot under maize measurements over a four month period showed that while the moisture content of the top foot of soil varied by a factor of 2 : 1, the variation in the layer of soil between 2 and 4 feet deep was 1·5 : 1. Unfortunately no measurements were made at greater depths, below the root zone, where the soil moisture would not be subject to transpiration losses. Measurements over the same period on a bare plot, however, indicate that in the absence of transpiration losses, the variation of moisture content decreases more rapidly with depth. In this case the variation in the top foot of soil was 1·7 : 1, while between 2 and 4 feet deep it was 1·2 : 1.

While it appears that the conductivity of the upper layers may vary appreciably, it must be noted that, due to evapo-transpiration losses of moisture, the conductivity of the upper layers is generally lower than that of the deeper ground. As a result, the percentage of ground current carried by the upper layers is less than is indicated by the figures quoted for homogeneous ground.

In the absence of more extensive data on soil moisture in South Africa, it is impossible to predict the order of ground wave field strength variations, and it is best decided by field strength measurements whether these variations are appreciable or not.

2·10 *Determination of ground conductivity field strength measurements*

In the case of homogeneous ground the conductivity can be deduced from the relative values of the ground wave field at a large distance from a transmitter, and the inverse distance field, that is, the field at a short distance from the transmitter, but outside its induction field. If the ground is not homogeneous the value of conductivity so obtained will be the average value effective over the whole transmission path, but it will not be valid for different transmission paths in the same region. In this case it is necessary to measure field strength that various distances along radials from a transmitter. The curves so obtained are then compared with theoretical propagation curves. The conductivity applying to each section of the theoretical curve is so chosen that the composite curve fits the measured propagation curve as closely as possible.

Ground conductivity measurement is subject to a number of possible errors, which are listed below :—

- *i* Errors due to variation of k, the effective increase of the earth's radius
- *ii* Errors of observation
- *iii* Instrumental errors, such as variation of the calibration of the field strength meter, or variation of the power radiated by the transmitter
- *iv* Errors due to local effects, in the case of measurements made in the vicinity of hills, buildings or overhead wires
- *v* Errors in the calculation of diffraction over uneven ground.

Errors in field strength measurement cause corresponding errors in the deduced value of ground conductivity. When measurements are made under conditions such that field strength is not largely dependent on conductivity, small field strength errors cause large errors in conductivity, which in turn produce large errors when the results are applied under conditions such that field strength is largely dependent on conductivity. Thus if measurements are made at a frequency so low that the results are applied to propagation at higher frequencies.

In general, field strength measurements determine the conductivity effective over the whole transmission path with greater accuracy than over any section of it. The accuracy with which the conductivity of a section of the transmission path is determined, decreases as the distance from the transmitter increases.

3. FIELD STRENGTH SURVEY IN SOUTH AFRICA

3·1 *Equipment*

A field strength meter, with a frequency coverage from 60 kc/s to over 1 mc/s, and capable of measuring field strengths ranging from several volts per metre to less than one microvolt per metre, was constructed in the Telecommunications Research Laboratory. This equipment, powered by a six volt accumulator, was mounted in a wireless van obtained on loan from the South African Air Force (SAAF). A block diagram of the field strength meter is given in Fig. 17. The meter comprised a receiver and a calibrator. The receiver was a conventional superheterodyne, with a beat frequency oscillator, and a diode voltmeter as an output indicator. An audio filter with a bandpass of about 50 c/s could be switched into circuit under conditions of low signal to noise ratio. The aerial was a 4 foot diameter, tuned, shielded loop. In use, the loop was raised 10 feet above the roof of the van, and rotated from inside the van.

The calibrator was carefully shielded to prevent leakage into the receiver section. The calibrating signal was adjusted manually, measured by a diode voltmeter, and then applied, through a decimal attenuator, to a small resistance in series with the loop.

When measuring the field strength of a signal, the loop was turned to the position of maximum pick-up and the output indication noted. Then with the loop in the minimum position, the calibrating signal was injected and adjusted to produce the same reading on the receiver ouput meter. The field strength was then indicated by the calibrator meter reading and the attenuator setting. This method of measurement ensured that the input to the receiver was the same for calibration and reception, both as regards amplitude and signal to noise ratio. (This is not the case when a dummy aerial is used for calibration, or when the output indications of the two signals are matched by the adjustment of an attenuator in the receiver section.)

The field strength meter was calibrated by measurement of a known field set up by a signal generator in conjunction with a standard loop. The calibration of the instrument was checked several times a year for the duration of the field strength survey, and the maximum deviation noted was 3 per cent. Fluctuation of battery voltage caused no change in calibration. With decreasing supply voltage, the receiver oscillator failed before there was any change in the response of the calibrator meter. The calibration of the loop aerial was found to be unaffected by its proximity to the van, hence independent of the orientation of the van.

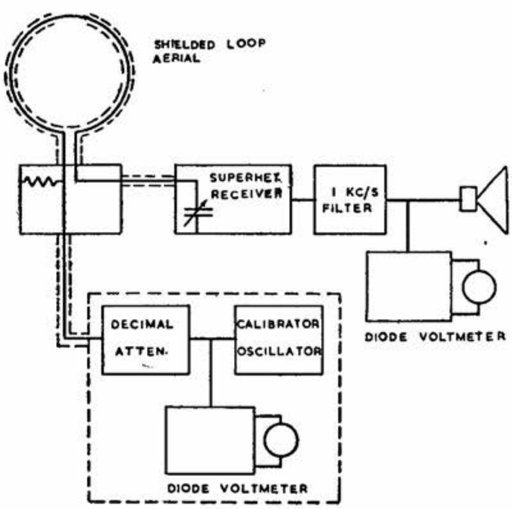

Fig. 17—Schematic diagram of field strength meter

3·2 *The field strength survey*

The field strength survey of South Africa was carried out by measuring the field strengths of existing transmitters below about 1 mc/s. These were the South African Broadcasting Corporation (SABC) transmitters, the Civil Aviation m.f. beacons, the S.A.A.F. m.f. beacon at Zwartkop and the South African Railways and Harbours (S.A.R. and H.) marine beacon at Swakopmund. In addition, measurements were made on the Decca transmitters on the occasion of the South African Decca Trials in 1950.

For purposes of the survey the Union was divided into sections, and the survey of each section was completed before the next was begun. The sections overlapped to a certain extent, and field strength measurements at the boundaries were generally repeated at intervals ranging from several months to over a year, as a check on seasonal variations.

The field strengths of all the transmitters in a section were measured concurrently. Measurements were made along roads radial to each transmitter, and on roads joining the radials, so that the information obtained should apply to propagation over the whole section, and not merely to propagation over a few straight-line paths in the section. A sufficient number of measurements was made so that errors, and field strength variations due to local effects, would average out. Measurements were generally made at intervals of 5 to 10 miles, except near the transmitters, where the intervals were shorter. The measurement positions were located on maps, and the distance to each transmitter was measured. At very short ranges, where large scale maps were not available, distances were measured directly with the aid of the van's mileage gauge. All measurements were made as far as possible from buildings and overhead wires. Apart from this consideration the measurement positions were not specially chosen, the measurements were made on hills and in valleys at random.

Particular attention was paid to conditions near each transmitter, as the effect of a local irregularity which subtends a large angle at the transmitter cannot be averaged out by taking a large number of measurements. In many cases, particularly at the higher frequencies, it was necessary to obtain a complete polar diagram of field strength in the immediate vicinity of the transmitter.

Measurements were not made under conditions of high atmospheric noise level, or when a large sky wave component of the signal was present. In the summer months atmospheric noise frequently made measurements after noon impossible. The measurements made at the end of each day were generally repeated the next morning, in order to keep a check on the magnitude of errors and short term field strength variations. Where necessary, the transmitters were monitored so that field strength measurements could be corrected for variations in radiated power. Aerial current readings were taken at regular intervals by the transmitter staff, and in two instances automatic recorders were installed.

Measurements were made on a total of about 40 transmitters. The locations and frequencies of these transmitters are listed in Table I. Several hundred field strength measurements were made on each transmitter, at ranges up to 500 miles, and in all, 40 000 miles of road were covered.

TABLE I

	Location	*Frequency in kc/s*
S.A.B.C. transmitters	Pretoria	863
	Maraisburg	638/782
	Welgedacht	1 025
	Bloemfontein	620/808
	Pietermaritzburg	691
	Durban	800
	East London	1 034
	Grahamstown	872
	Port Elizabeth	962/773
	Kimberley	932
	Cape Town	601/788
Civil Aviation m.f. beacons	Pietersburg	230
	Germiston	380
	Palmietfontein	370
	Carolina	320
	Bloemfontein	245/265
	Ladysmith	355
	Durban	390
	East London	235
	Port Elizabeth	400
	Kimberley	365/385
	Victoria West	220
	Beaufort West	350
	George	325
	Cape Town	205
	Piketberg	360
	Keetmanshoop	260
	Windhoek	270
S.A.R. & H.	Swakopmund	291·5
S.A.A.F.	Zwartkop	410
Decca transmitters	Witwatersrand	127·5/85
	Cape	127·5/85

RESULTS

Measured values of field strength were corrected for transmitter variations as shown by the aerial current readings. Correction was also made for diffraction losses due to mountains sufficiently prominent, or sufficiently near to the transmitter or receiver. The results were then plotted as propagation curves, and the ground conductivity deduced by comparison with theoretical curves.

Typical propagation curves are illustrated in Figs. 18-23. The measured values are indicated by dots, while the full line curves are theoretical propagation curves drawn for comparison.

The propagation curves in Figs. 18 and 19 show different degrees of spread of the measured values.

The propagation curve from Kimberley to Zeerust is an extreme case, and such a high degree of spread did not frequently occur, even in hilly country. The ground between Kimberley and Zeerust is fairly flat and open. Most of the measurements up to a range of 60 miles, and several beyond this range, were repeated and confirmed at a later date. It appears that the spread of field strengths was due to local variations of ground conductivity.

The field strengths plotted in Fig. 20 apply to transmission at 380 kc/s from Germiston to Harrismith.

The field strength shows a marked decrease over a few miles at a range of 20

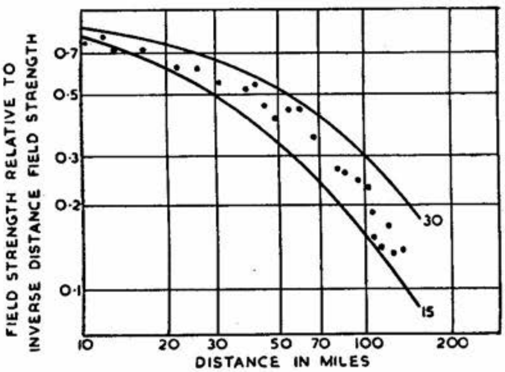

Fig. 18—Ground wave propagation at 810 kc/s from Bloemfontein to Jamestown

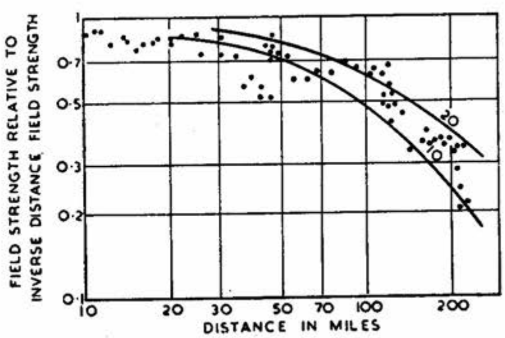

Fig. 19—Ground wave propagation at 365 kc/s from Kimberley to Zeerust

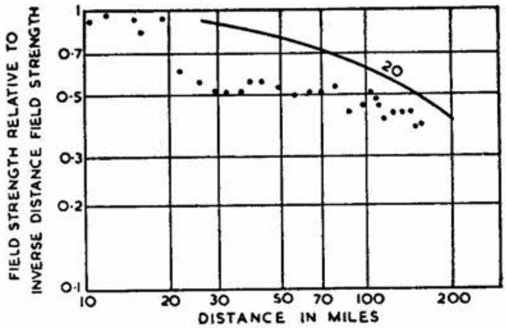

Fig. 20—Ground wave propagation at 380 kc/s from Germiston to Harrismith

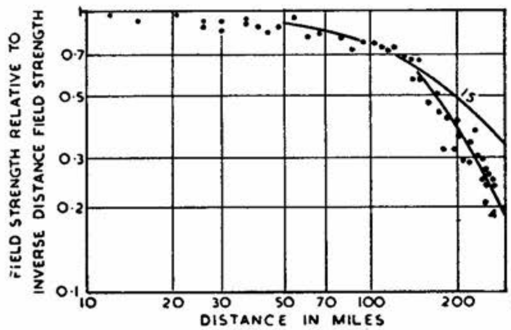

Fig. 21—Ground wave propagation at 245 kc/s from Bloemfontein to East London

miles from the transmitter, and then gradually recover. This effect is due to a small region of very low conductivity extending from about half way between Meyerton and Heidelberg, to about 10 miles east of Heidelberg. Apart from this region, the conductivity between Germiston and Harrismith has been found by other measurements to be about 20×10^{-14} e.m.u. The theoretical propagation curve for this value of conductivity is drawn in Fig. 20 for comparison. Similar effects have been observed on transmission over this region from S.A.B.C. transmitters at Maraisburg and Welgedacht; in the case of transmission at 1 025 kc/s from Welgedacht the drop in field strength was about 10 db.

Fig. 21 illustrates propagation at 245 kc/s over inhomogeneous ground from Bloemfontein to East London.

The composite theoretical curve was constructed by Millington's method. The conductivity value, 4×10^{-14} e.m.u., applying to the second section of the curve, was determined separately by measurements on the 235 kc/s transmitter at East London. These results are in agreement with Millington's theory, and this theory has been adopted to deal with all cases of propagation over inhomogeneous ground. In most cases it was impossible to measure the conductiv-

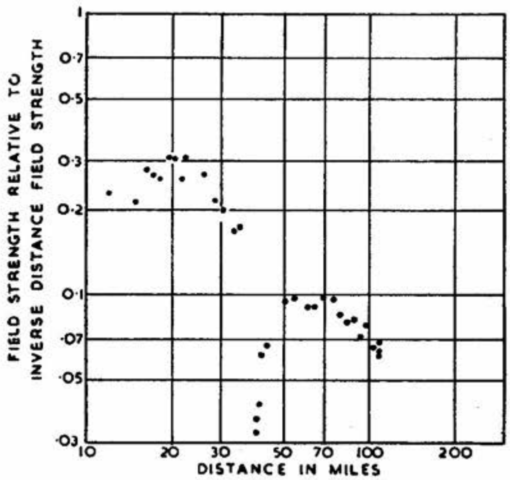

Fig. 22—Ground wave propagation at 325 kc/s from George to Beaufort West, over mountain ranges distant 5 and 40 miles from the transmitter

ities of the sections separately,but where this was done no disagreement with Millington's theory was found.

Field strengths of the 325 kc/s transmitter at George, measured from George to Beaufort West, are plotted in Fig. 22.

The transmission path crosses two main mountain ranges distant 5 miles and 40 miles from the transmitter, and their effect on the field strength is clearly seen. The diffraction losses have been calculated, and in Fig. 23 the field strengths have been corrected for these losses, showing the type of propagation which would occur in the absence of the mountains. The conductivity of the second section of the curve agrees with that obtained by measurements on the 350 kc/s transmitter at Beaufort West.

It was mentioned in Section 3·2 that measurements made at the end of each day were generally repeated the next morning. In addition, certain measurements were repeated at intervals of up to two months. Analysis of these repeated measurements, made at over 300 different positions throughout the area covered by the survey, shows that in 95 per cent of cases the deviation from the mean value was less than 10 per cent, and in 90 per cent of cases less than 5 per cent. These figures show that the effects of errors and short term variations of ground conductivity and the refracting properties of the atmosphere were small. The large spread of field strengths apparent in many of the measured propagation curves was evidently due to local effects. Measurements at about 100 check points in all parts of South Africa were repeated at intervals ranging from several months to over a year. In 88 per cent of cases the deviation from the mean was less than 10 per cent, and in 72 per cent of cases less than 5 per cent. It is concluded that seasonal variation of ground wave propagation conditions may be neglected.

In those areas where measurements were made on a group of transmitters of different frequencies, ground conductivity was found to vary with frequency. For each transmission path on which measurements were made at more than one frequency, a set of conductivity values corresponding to the different frequencies was obtained. These values were expressed relative to the conductivity at 500 kc/s, obtained by interpolation. These relative conductivity

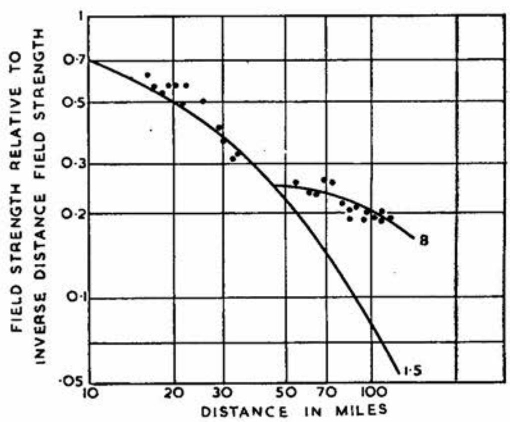

Fig. 23—Propagation from George to Beaufort West as in Fig. 22, but corrected for diffraction losses

values, for all groups of transmitters and transmission paths where comparative measurements were made, are plotted in Fig. 24.

The full line curve is drawn to give best agreement with these points, and represents the average conductivity-frequency relation in the regions where comparisons were made. The eight groups of transmitters on which comparative measurements were made are listed in Table II. It must be noted that the conductivity-frequency curve is based on a limited amount of information.

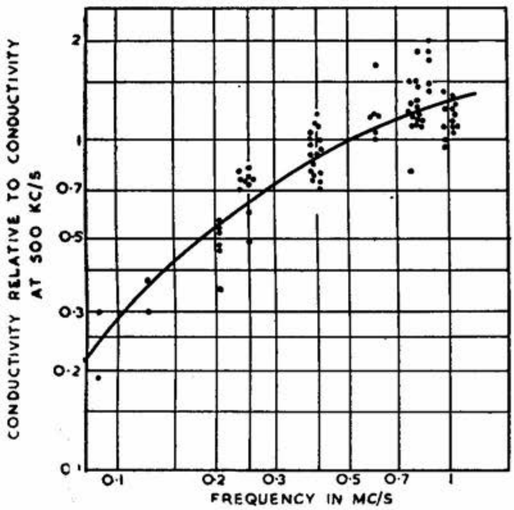

Fig. 24—Relation between ground conductivity and frequency in areas surrounding the eight groups of transmitters listed in Table II

The information obtained from each area applies to only a section of the curve, limited by the highest and lowest transmission frequencies of the group of transmitters in that area. Over large areas no comparisons were made, as the existing transmitters did not differ sufficiently widely in frequency. The relative conductivity at about 100 kc/s was obtained from measurements on the Decca transmitters on only two transmission paths—Johannesburg to Jamestown, and Cape Town to Victoria West.

The results of the ground conductivity measurements have been presented in the form of a ground conductivity map, which is reproduced in Fig. 25.

The map indicates the value of ground conductivity effective to propagation at 500 kc/s, the measured values having been transformed in accordance with the conductivity-frequency curve in Fig. 24. This curve is not necessarily valid for conditions in South West Africa and the North Western Cape Province, where no comparisons of conductivity at different frequencies were made, but it represents the only information available, and is assumed to hold for all areas covered by the survey.

A larger and more useful map is in the course of preparation, and will be obtainable on application to the Telecommunications Research Laboratory. The original field strength measurements will not be published, but are available in the records of the above Laboratory should they be required for any specific purpose.

Except where available transmitters were very widely spaced, the ground conductivity indicated by the map is the average of the values obtained by field strength measurements on a number of transmitters. The map indicates the average conductivities effective over fairly large areas, and cannot be used to predict local conditions with accuracy.

The region of low conductivity near Heidelberg, which has been previously mentioned, is not shown on the map, as its extent is small and the conductivity

TABLE II

Groups of transmitters on which comparative ground conductivity measurements were made :—

	Location	*Frequency in kc/s*
1	Pretoria	863
	Zwartkop	410
2	Welgedacht	1 025
	Germiston	380
	Springs	127·5
	Kempton Park	85
3	Bloemfontein	620
		808
		245
4	Durban	800
		390
5	East London	1 034
		235
6	Port Elizabeth	962
		773
		400
7	Cape Town	600
		205
		85
	Sea Point	127·5
8	Kimberley	932
		365

indeterminate. A similar region of low conductivity exists near Bloemfontein, and there are doubtless others, which, being remote from transmitters, were not detected.

In general, the resolution and accuracy of the map are least in regions remote from the transmitters on which the measurements were made, where propagation conditions approach the long wave limit, or where measurements were made on only one transmitter. The survey in many parts of South West Africa and the North Western Cape Province was carried out under such conditions, as the few available transmitters were very widely spaced, and the frequencies low.

In many cases the boundaries between regions of different conductivities were not well defined by the measurements, and this must be borne in mind when considering propagation along a boundary. When a region having a particular conductivity was also distinguished by some topographical feature, the conductivity boundary was generally drawn to conform with the topographical boundary, after verifying by measurement that the boundaries were coincident at several points. For example, referring to the region of low conductivity extending from Worcester to Van Rhynsdorp, measurements on several radials from Cape Town showed that on these radials the boundaries of the low conductivity region coincided with the boundaries of a well defined mountainous region. Consequently, between the radials, the conductivity boundary was drawn to coincide with the boundary of the mountainous area.

An attempt has been made to correlate the ground conductivity map with the

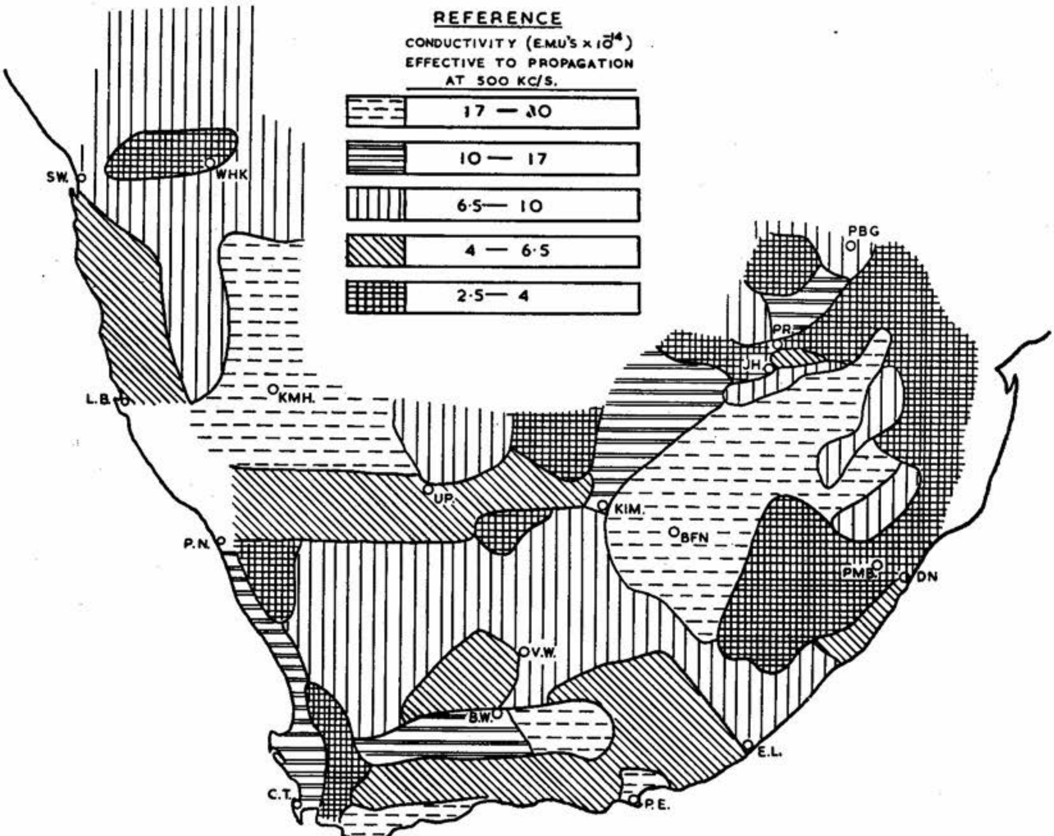

Fig. 25—Ground conductivity map of South Africa

geological map, soil map, and resistivity values contained in C. F. Boyce's paper[5] on the earthing of telephone systems, but with little success. It must, however, be remembered that local measurements of resistivity, at a fixed temperature and moisture content, show large variations for the same type of soil or rock. Furthermore, in addition to the type of soil, its depth, and the type of rock, ground conductivity depends to a large extent on the moisture content, and extensive data on the moisture content of the soil in South Africa are not available. It is apparent from the map that the conductivity effective to ground wave propagation is influenced by the roughness of the ground, the conductivity being lower than average wherever broken ground occurs.

5. CONCLUSION

Ground wave propagation characteristics at frequencies up to 1 mc/s can be predicted with the aid of the ground conductivity map and the conductivity-frequency curve, though the limitations of the latter must be borne in mind. Norton's propagation curves and Millington's theory of propagation over inhomogeneous ground were used in the determination of ground conductivity, and hence they should also be used in field strength predictions from the ground conductivity map. In mountainous terrain it may be necessary to take diffraction losses into consideration. Local effects near the transmitter or receiver may cause the field strength to deviate from the predicted value; these deviations are generally less than 3 db.

The results of the field strength survey indicate that field strength variations due to time variations of ground conductivity or of the refracting properties of the atmosphere were negligible.

6. ACKNOWLEDGMENTS

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8. APPENDIX

Diffraction calculations

The calculation methods presented here are based on J. A. Fejer's[11] analysis of the problem.

Fig. 26 illustrates the geometrical considerations relating to propagation over

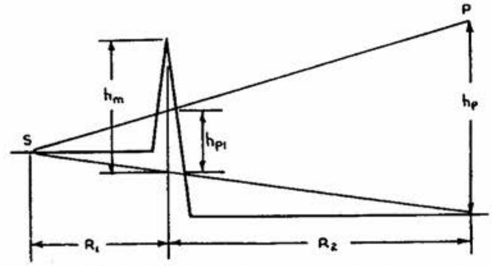

Fig. 26—Illustrating quantities appearing in equation 5

a single range of mountains crossing the transmission path at right angles, and extending for a long distance on each side of the transmission path. The case is considered is the general one in which the ground on both sides of the mountains is not assumed to be at the same level.

Transmission takes place between S and P, S being at ground level and P at a height h_p above the ground. Assuming the ground to be a perfect reflector, the diffraction loss factor is given approximately by the relation.

$$F_D = \frac{e^{j\pi/4}}{\sqrt{2}} \left[\int_{-\infty}^{u(-h_m-h_{p1}} e^{-j\frac{\pi}{2}u^2} du + \int_{u(h_m-h_{p1})}^{\infty} e^{-j\frac{\pi}{2}u^2} du \right] \quad \ldots \quad \ldots \quad \ldots \quad 5$$

where F_D is the diffraction loss factor, defined in Section 2·6,

$$u(h) = h\sqrt{\frac{2}{\lambda R_{12}}} \quad ,$$

$$R_{12} = \frac{R_1 \; R_2}{R_1+R_2} \quad ,$$

and λ=wavelength in the same units as h and R.

The above relation is an approximation, but the errors involved are small provided thst R_1 and R_2 are large compared with the wavelength and with the heights of the mountains.

When both the transmitter and the receiver are at ground level, *5* becomes

$$F_D = \sqrt{2}\, e^{j\pi/4} \int_{u(h_m)}^{\infty} e^{-j\frac{\pi}{2}u^2} du$$

In this case the diffraction loss factor depends only on the quantity $h_m{}^2/\lambda R_{12}$. Diffraction loss factors corresponding to different values of $h_m{}^2/\lambda R_{12}$ are given in Table III.

TABLE III

$h_m{}^2/\lambda R_{12}$	F_D
0·001	0·95
0·01	0·87
0·03	0·79
0·1	0·64
0·3	0·49
1·0	0·31

When two mountain ranges cross the transmission path at right angles. the expression for the diffraction loss factor is relatively complex, and is not reproduced here.*

It has, however, been found that the diffraction loss factor is in this case given approximately by the product of the individual factors associated with each of the mountain ranges considered separately. This is subject to the condition that all distances involved, including the distance between the two ranges, be large compared with the wavelength and with the heights of the mountains.

* In the final expression of Fejer's analysis the factor $R_1+R_2+R_3/R_1+R_2$ should be $\sqrt{(R_1+R_2+R_3/R_1+R_2)}$. The error is due to the omission of a factor $e^{\frac{-j\pi y^2}{\lambda(R_1+R_2)}}$ in equation *11* of the analysis. This factor is necessary to express the change of phase of V_2 in the y direction.

DISCUSSION

T. G. E. COCKBAIN (Associate): Mr Vice has made a very real contribution to the radio engineering field in South Africa in his paper on the ground constants in the Union, with its accompanying map of soil conductivities. I am not capable of commenting on the theory of Mr Vice's paper, but from the practical viewpoint, I see that the task of engineers employed in medium- and low-frequency work will be made considerably easier by the availability of this ground constants map. Happily the propagation in the low- and medium-frequency bands is less affected by the dielectric constants of the earth than at higher frequencies. and in any case this factor appears to have a sufficiently close tie-up at m.f. with ground conductivity for a satisfactory value to be deduced therefrom.

It occurs to me that in some places in the Union the ground conductivity changes so rapidly that an effect similar to coastal refraction might reach measurable proportions giving noticeable errors in direction-finding bearings. One such area could be along the eastern border of the Orange Free State. Airborne direction-finding is still an important factor in aerial navigation in this country, and it is in this connection that I see the greatest application of Mr Vice's map in the S.A. Air Force. Up to the present time medium-frequency aeronautical beacons have been sited to suit the aeronautical traffic lanes, and their frequencies allocated in a rather haphazard manner. Now, with this information on ground constants available, it should be possible to allocate the lower frequencies to stations in the worst conductivity areas, and furthermore, to calculate with a reasonable degree of accuracy, just what the coverage of a particular beacon will be.

Brief reference to some examples will show what I mean.

Consider two areas of ground conductivity $(6{\cdot}5 \text{ to } 10) \times 10^{-14}$ e.m.u. to the North-East of Victoria West, and $(2{\cdot}5 \text{ to } 4) \times 10^{-14}$ e.m.u. around Pietermaritzburg. Taking the extreme values, we find that the distances from 1-kW m.f. beacon with a top-loaded vertical radiator at which the field strength will be 100 micro-volts per meter work out like this.

Frequency kc/s	100 micro-volts per meter distance from beacon	
	Victoria West	Pietermaritzburg
500	200	100
300	300	170
150	420	330

Should a range of 300 miles be required of the beacon, it can clearly be seen that the frequency allocation for the Pietermaritzburg beacon would have to be at the extreme low end of the m.f. band, while that of the Victoria West beacon would be as high as 300 kc/s. Should the allocation of frequencies be made the wrong way round, Victoria West would have a spectacular range of over 400 miles, but the area served by the Pietermaritzburg beacon would be reduced to some 170 miles radius. This example is not such an extreme case as could be obtained by taking, say Pietermaritzburg and Bloemfontein but was selected because the actual beacon frequencies at Durban and Victoria West are 390 kc/s and 220 kc/s respectively. This poses the question as to whether these frequencies are wisely chosen, or whether they should be allocated the other way round.

The map produced by Mr Vice provides some surprises in the matter of ground conductivities. It has been my completely erroneous impression, for instance, that the inland areas would have a lower conductivity than say a coastal area such as Zululand, yet we find the worst conductivities in Northern Natal, and the best area of any great size on the dry plains of the Orange Free State. It is clear that we will have to think again on several projects now we have this valuable information at our disposal. This particularly applies to the areas not previously covered in superficial checks previously made. The results of this survey will be most useful, when read in conjunction with the noise level figures to be produced by Telecommunications Research Laboratory, in the planning of any low- or medium-frequency radio navigational aids, such as Decca l.f. Loran or conventional Loran.

Before concluding, I should like to ask Mr Vice if any directional measurements were made at the same time as the field strength observations, and also what precautions were taken against the inclusion of sky wave components in his measurements, especially at the end of long paths where the frequency of the station being observed was comparatively high.

R. W. Vice (*in reply*) : Unfortunately there are no figures available on the magnitude of refraction effects, as the field strength survey did not include directional measurements.

With regard to Captain Cockbain's suggestion that the lower frequencies, due to their smaller ground losses, should be allocated to beacons in low conductivity regions, there are several other factors which must be considered. These are :—

a The atmospheric noise level is higher at the lower frequencies.
b For a given transmitter, aerial, and earth system, less power is radiated at the lower frequencies.
c The ground conductivity is generally lower for the lower frequencies.

In order to ensure that only the ground wave component of field strength was measured, measurements at long ranges were not made before 8 a.m. or after 5 p.m. In the few cases where fading did occur, the signal was measured over several fading cycles and the mean value taken.

G. E. DAMANT (*contributed*): The author of this very interesting paper has pointed out that there is little agreement between the ground conductivity map which he has produced, and the resistivity values obtained by Boyce. The discrepancy is apparently ascribed to large local variations of resistivity in soil or rock of the same type. However there is another feature of Mr Vice's map which seems to call for some explanation.

According to Smith Rose, the effect of moisture content on soil conductivity is large, but it is noteworthy that, generally speaking, areas which have a low conductivity on the map correspond to the regions of highest rainfall, whereas desert or semi-desert regions have the highest conductivity. Thus we find that the country running down from the Eastern Transvaal to, and including, Basutoland, with an annual rainfall of 30 to 40 inches, has a conductivity in the range $(2{\cdot}5 \text{ to } 4) \times 10^{-14}$ e.m.u., and that the Garden Route country, with an annual rainfall of the same order, has a conductivity in the range $(4 \text{ to } 6{\cdot}5) \times 10^{-14}$ e.m.u.; whereas the region around Keetmanshoop, with an annual rainfall of less than 10 inches, has a conductivity in the range $(17 \text{ to } 30) \times 10^{-14}$ e.m.u.

It will also be observed that the areas of low conductivity on the map correspond even more strikingly with mountainous regions. The apparent inverse relationship between ground conductivity and rainfall, taken in conjunction with the close agreement between low conductivity areas and mountainous country, suggest that insufficient allowance has been made, when computing ground conductivities, for the reduction in field strength caused by the presence of mountains.

The theory on which the diffraction calculations are based considers parallel lines of mountains crossing the transmission path at right angles. Is it permissible to apply the results of this theory to regions where broken country extends in depth; and where the mountains and hills have random orientation and do not conform to the parallel range assumption?

It would be appreciated if the author would provide further information on these points.

R. W. VICE (*in reply*): The lack of correlation between the ground conductivity map and the data presented in Boyce's paper is ascribed, not only to the wide values of resistivity applying to the same type of soil or rock, but also to the fact that the information contained in Boyce's paper does not include all the factors which contribute to the ground conductivity effective to radio propagation. Boyce's paper contains resistivity values for different types of rock and soil (measured at a fixed temperature and moisture content in the latter case), a soil map and a geological map. This information cannot determine the ground conductivity effective to radio propagation, which depends also on the frequency, the soil moisture content at various depths, the soil depth, and the magnitude of diffraction losses.

At first sight it is surprising that the regions of high rainfall should be low conductivity regions. Moisture content is however, only one of the determining factors of effective ground conductivity, and correlation between conductivity and moisture content is not necessarily to be expected if the other factors are disregarded. Boyce, for instance, refers to certain soil types in Natal and the Eastern Transvaal —these soils are deep and have a high moisture content, but the salt content has been reduced by the heavy rainfall, resulting in a low value of conductivity. The desert and semi-desert soils generally have a high salt content, and Boyce's figures for resistivity at fixed moisture content are, in general, lower for these soils than for soils in the high rainfall areas. The moisture content itself must be regarded as unknown;

it is not completely determined by the rainfall, as the type of soil and the magnitude of evaporation and transpiration loses are also important determining factors.

The effective conductivity of hilly and mountainous regions is probably due largely to diffraction losses. There is, however, no question of insufficient allowance being made for these losses. It is emphasised that the map indicates the *effective* ground conductivity, which includes the effects of diffraction losses due to uneven ground. Except where diffraction losses were not typical of the whole region concerned, no allowance at all was made for them.

The methods used to calculate diffraction losses involve certain approximations and simplifying assumptions, and cannot be applied to cases involving propagation over extended regions of a broken or mountainous nature.

F. J. Hewitt (*Associate Member*) : I am grateful for this opportunity of congratulating Mr Vice on the presentation of his paper ; and also on the actual survey itself and the development of the necessary equipment.

This work was one part of the general study of factors affecting radio wave propagation in South Africa undertaken by the Telecommunications Research Laboratory of the C.S.I.R.

It was inspired initially by the great advances in aviation during the war and the desire for international standardisation of radio aids to aerial navigation.

The possibility of long range aids to navigation has been under active consideration internationally since the war and it was important that we in South Africa should know something of the performance of these aids *over land* as opposed to over sea, and in our high atmospheric noise levels.

I will not say any more on this aspect as it has been referred to also by Captain Cockbain of the S.A.A.F.

There is one other point I should like to emphasise. This survey was undertaken to provide information on average conditions over the whole country and was not intended to provide detailed information such as might be required for the selection of a good earthing system for a transmitter aerial. This is a domestic matter for the organisation concerned and Mr Vice's paper can only assist in the general planning of radio coverage.

However on this subject I should like the author's comments on whether or not he can draw any conclusions as to the effect of the local terrain on the performance of existing transmitter sites and whether this information would be useful in the selection of new sites. The views of users of low- and medium - frequency transmitters in this country would also be of interest.

R. W. Vice (*in reply*) : It was noticed that for a transmitter sited at the edge of a hill, the field radiated forward over the neighbouring low ground was greater than back along the hill. In the case of the S.A.B.C. transmitter at Pietermaritzburg, the field radiated over the valley to the East was twice as great as the field along the high ground to the West, and similar effects were observed on the Grahamstown transmitter. Unfortunately, very few of these cases were encountered, and no definite conclusions on this point can be reached.

ITEM OF TECHNICAL INTEREST

Improved ventilation on a winder motor

By J. K. GILLETT (Member)

The sole 3 240-h.p., semi-automatic Ward Leonard rock hoist at Premier (Transvaal) Diamond Mining Company, Limited, was originally operating on a duty of hoisting 12 800 tons of ore per day form a depth of 1 420 feet. This involved a net load of 11·8 tons per trip for 58 trips per hour over $18\frac{3}{4}$ hours per day, the duty cycle being—

Acceleration	12 seconds
Full-speed wind	30 seconds
Deceleration	12 seconds
Tipping and decking ...	8 seconds
Trips per hour	58

$5\frac{1}{4}$ hours a day was allowed for routine maintenance and adjustments and other minor stoppages, for the above tight schedule did not permit of any unmeditated interruptions.

At that time, power restrictions were not even dreamt of, and all went well until various means eventually had to be considered to limit the maximum demand over the restricted hours between 8 a.m. and 9 p.m.

This mine, however, does not lend itself to an easy manipulation of its load, since there is only one main hoist, one compressor, and one large pump in operation at any one time. The reduction plant is not capable of being operated in smaller sections than 25 per cent of the whole, and is entirely unlike a gold mine plant where single tube mills can be shut down to give an easy regulation of the mine maximum demand. Moreover, to shut down a 25-per cent section of the reduction plant is a lengthy business, whilst an involuntary or sudden shutdown might take as much as 12 hours to clear the resulting blockages.

The mine, therefore, had to rely to a large extent for the control of its maximum demand by varying the winding trips per hour. By introducing an adjustable time-delay device into the onsetter's pushbutton circuit, it was possible to reduce the number of trips to 35 per hour. This soon led to production complications, since the head-gear bin—the only means of effecting a storage reserve for the reduction plant—is only of 2 000 tons capacity—say 4-hours supply. Some means had to be devised of piling up an ore reserve during the unrestricted power period, and this meant, of course, intensified hoisting.

After some deep cogitation and calculation, and insistent correspondence with the manufacturer, it was decided to increase the full speed of the hoist from 2 500 ft/min to 3 000, and to improve the duty cycle to—

Acceleration	10 seconds
Full-speed wind	25 seconds
Deceleration	10 seconds
Tipping and decking ...	5 seconds
Number of trips per hour ...	72
Net load of rock	11 tons

With this schedule an accelerating D.C. current of 8 000 amperes was sometimes observed.

Now, one of the limiting factors on a heavy-duty hoist is the temperature rise of the motor windings. Very soon, for this was the summer period with a maximum shade temperature of 35°C, things began to warm up, and the motor was festooned with thermometers. One day, at 4 a.m., a temperature of 105″C was logged; this probably indicated a temperature of 115°C at the inner surface of the windings, and the duty had to be eased off until the machine cooled down somewhat.

The manufacturer, when informed, began to shake his head and look worried, but mining engineers refuse to be beaten by such trifles, and insisted that a solution be found —and quickly, because tonnage might suffer.

The mine engineering staff thereupon began to develop an interest in the finer points of the ventilation of rotating machinery, and one or two fundamental facts soon came into evidence. Of these, the main item was that with the normal, reversing winder motor with a built-in fan, efficient cooling ceases whilst the machine is decking, accelerating and decelerating. As can readily be realized from the foregoing figures, this period, in this instance, is a considerable portion of the winding cycle. The obvious deduction was, therefore, that the cooling period must somehow be extended. Another interesting point was that the fan action of the rotating cheeks of the winder drum very seriously interfered with the induced draught through the motor; a bucking of the two airstreams was noticed.

The outcome of these basic observations was—to the horror of the manufacturer—that the mine removed the fan impellers, boxed in the end windings of the coupling side of the motor, and installed an independent 5-h.p. fan to provide a continuous stream of air through the machine from the coupling to the commutator end. The most gratifying result was the immediate reduction of recorded motor-winding temperatures by at least 30°C, no matter how hot a day it might be. It is also worthy of recording that this hoist recently lifted 17 500 tons of rock over a continuous period of 22 hours without any obvious heating malady.

It is to be noted that it is essential for the independent 5-h.p. fan to be connected up to the secondary trip circuit of the winder, or at least to a siren alarm, since the motor has been deprived of its inherent cooling system.

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