AN EVALUATION OF THE ACCURACY OF DECCA AS A MEANS OF DISTANCE MEASURING OVER LAND

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Summary

From results of trials on the Danish Decca Navigator Chain (1949), made available to the author by the courtesy of the Danish Hydrographer and of the Danish General Post Office, it has been possible to evaluate the accuracy of Decca as a means of measuring an unknown distance over land.

In this particular case, it is concluded that distances of 162, 157 and 171 kilometres between two Decca transmitters could be measured with absolute accuracies of 1 part in 54,000, 1 part in 63,000 and 1 part in 90,000, respectively (see fig. 4).

There is no absolute guarantee that these figures can be regarded as representative of all possible circumstances. However, taking into consideration (i) the limited accuracy of the equipment used, (ii) the limited number of observations, (iii) the limited amount of information on ground conductivity and (iv) the results of other trials to be mentioned in this paper, it is believed that these are most valuable indications of the degree of accuracy that can be expected from a relatively small amount of information. Undoubtedly even more accurate results could have been obtained had there been available specially constructed survey equipment of the latest type, instead of just the normal navigation equipment used for these trials.

As the theory, applied in this analysis, is in such close agreement with the facts, there can be no doubt that it can be applied with still more confidence under the more favourable circumstances when propagation between transmitters and receviers takes place over ground of homogeneous conductivity, or, even better, entirely over water. In the latter case, and making use of survey equipment, it does not appear too optimistic to expect an accuracy in the order of 1 part in 100,000 in a distance of two to three hundred kilometres to be measured by Decca.

There are a number of electronic systems suitable for geodetic work ; all such systems have certain characteristics which make them particularly suitable for a certain type of geodetic application. Combinations of different applications are generally possible to only a limited extent. The aim of this paper is to show that Decca, in addition to position fixing and contrary to a widely held opinion, can also be used for distance measurement over land, provided that a certain amount of information is available on the electrical conductivity of the ground.

1. *Introduction*

In geodetic applications, an electronic system may be used either (1) for the measurement of a distance, or (2) for position fixing by determination of distances (circular system) or differences of distances (hyperbolic system), in both cases respective to radio transmitters of known or adopted coordinates.

Actually, all systems measure time or time differences, which must be translated into distances. As in other geodetic work, the required distance is the distance measured along a geodetic line on the surface of a reference ellipsoid. The radio waves actually do not travel along that path and it is therefore necessary to known the curvature of their path and the travelling speed along it.

In vacuo the radio waves are supposed to travel at constant speed C along a straight line*. In the earth's atmosphere, it is known that there is considerable departure from this straight line and also that the speed is not constant. Unfortunately it is physically impossible to trace the actual path and speed in the atmosphere and one has, therefore, to depend on theoretical considerations; the outcome of such theories, however, can be checked against accurately known geodetic distances.

Theories on radio wave propagation are based on the supposition that the waves travel in a plane defined by the earth's (ellipsoid's) centre and the antennas of the transmitter and receiver.

Taking into account other sources of errors and uncertainties, the difference in length between the line of intersection of this plane with the ellipsoid (geoidal section) and the corresponding length of the mathematically defined geodetic line, can be entirely neglected.

The travelling speed and curvature of the path in the above-mentioned plane depend mainly upon (*a*) radio frequency of transmission (*b*) meteorological conditions, and (*c*) electrical conductivity of the terrain over which the waves are travelling.

It should be emphasized, that in any theory on propagation, speed and curvature are related quantities; a certain assumed curvature with an associated propagation speed along that path, may lead to the same final result as another assumption of curvature with a different speed.

It is evident that the accuracy of any electronic system can be improved by:

1. Improvement of equipment (transmitter and receiver) design; this is a radio technical problem.

2. Improvement in knowledge on radio wave propagation; this is a physical problem.

Both are complex and difficult problems and are strongly interdependent, because clearly little can be gained by improving equipment design if propagation anomalies should be the limiting factor in final accuracy. The same argument applies, of course, in the reverse case.

Both problems have been mastered to a sufficient degree to allow some of the existing electronic systems to be used for certain geodetic applications. There

* Neglecting curvature of the Einstein-type in the gravity field, which is absolutely negligible for the distances under consideration.

is considerable evidence that propagation anomalies will be the limiting factor in future development, but space does not allow of discussion in much detail, neither on design, nor on propagation.

This paper will discuss one geodetic application only, being measurement of (long) distance; position fixing will not be discussed.

Until now, Shoran has been the system most widely used for this type of work. Trials under nearly ideally controlled conditions have shown that an *absolute* accuracy in distance measurement of 1 part in 100,000 can be achieved and even considerably higher accuracies have been claimed*. From very extensive work in Canada (see papers of Mr. J.E.R. Ross to be presented to this Conference and published elsewhere) it appears that, with an amount of control — instrumental as well as meteorological — that can be achieved in actual practice in the terrain. the present absolute accuracy is of the order of 1 part in 30,000 to 1 part in 50,000.

Other systems suitable for geodetic distance measurement are Raydist, Decca, Lorac and Rana. Little has been published regarding accuracy of Raydist, Lorac and Rana, and nothing on measurement of distances of any consirable length.

As to Decca, it is known that this system is likely to be capable of accurate distance measurement of a long (several hundreds of kilometres) distance over a water trajectory between two transmitters ; this, however, has not yet been proved by actual accurate trials. There seems to be a general feeling that Decca cannot be used to any great accuracy for distance measurement of a *land* path. This paper is to show that, provided a comparatively limited amount of ground conductivity information is available, Decca is capable of quite accurate distance measurement over *land*. As the conditions of propagation over *water* are much more favourable, there can be no doubt that distance measurement over water should be appreciably more accurate. Although there are no reasons to doubt this conclusion, it is still highly desirable to prove it by actual trials.

2. *Propagation of Decca waves.*

Decca (and also Raydist, Lorac and Rana) — in contrast to Shoran, which is a pulse-system — makes use of continuously transmitted waves; all measurements are based on phase-comparison of two transmissions. Decca frequencies are of the order of 100 kc/s.

As already stated, under idealized conditions (vacuo) the front of these waves would travel at constant speed C; C being the free-air velocity of electromagnetic waves. In actual practice the waves are travelling through the earth's atmosphere and, therefore, in order to be able to translate time differences (phase-differences) into distances, the frequency of transmission, the curvature of the earth, the conducting properties of the ground over which the waves are travelling and a number of other factors need to be taken into consideration.

Moreover, there are two main modes of propagation:

1. Directly from transmitter to receiver (*ground-wave*), and 2, via reflection by the ionosphere (*sky-wave*). For limited distances — in daylight up to about 400 kilometres — ground wave propagation only has to be taken into consideration.

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* In judging extremely high accuracy figures, it should be borne in mind that the basis of comparison is always a known geodetic distance; it should, therefore, be known whether it had or had not been possible to reduce this distance with sufficient accuracy from geoid to ellipsoid.

The combined effect of these factors results in a *phase-velocity* V — being smaller than C — at which the wave front actually travels from transmitter to receiver. Consequently — with respect to a theoretical wave front travelling at constant velocity C — in actual practice there will be a *phase lag* ϕ.

The theoretical value of ϕ along a path with a curvature equal to that of the earth, and the manner in which it varies over homogeneous ground with distance and frequency, may for different values of ground conductivity (σ) be computed from formulae of Norton and of Bremmer. In these formulae, ϕ is expressed in sexagesimal degrees and C is assumed to be 299776 km.-sec. In Decca applications it is more convenient to express ϕ in cycles of the so-called comparison frequency, one cycle being equal to 360°. Curves of this type have been computed by Mr. Schneider of the Decca Company and have been used in the analysis to be described in this paper; they are not reproduced in this paper, because it would take too much space to do so on a sufficiently large scale.

Fig. 1 gives a typical set of phase-lag curves over homogeneous ground for three different frequencies.

In fig. 2 phase-lag curves are given for transmission at 85 kc/s (frequency of Decca Master station) and for three different ground conductivities.

Figs. 1 and 2 are not drawn to scale and are only intended to show their general character. Fig. 2 also serves to explain the manner in which the actual curves have been used, as will be explained in an example in para. 3.

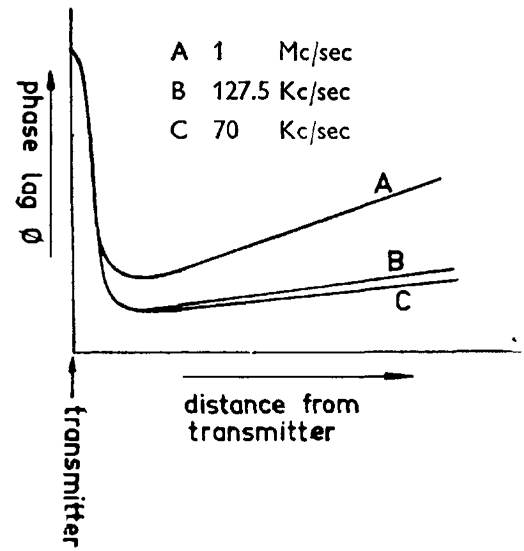

Fig. 1.

Observation 1 : Very close to a transmitter ϕ is determined mainly by the relative values of the static and induction components of the field; they are in phase opposition and phase quadrature, respectively, to the radiation component.

The amplitudes of the static and induction components, however, decrease with distance more rapidly than does that of the radiation component, so that at distances greater than one or two wavelengths, ϕ is determined mainly by the phase of the ground wave attenuation factor.

If measurements very close to a transmitter are avoided, this peculiarity does not introduce any practical difficulty.*

Observation 2: The adoption in the theory of a value for C is not very critical; the existing graphs are based on $C = 299776$ *km.-sec.* At the present time, the best known value of $C = 299793.1 \pm 0.2$ *km.-sec.* (Bergstrand, 1951). Adoption of this — or still another — value would result in different values of ϕ. In order to avoid recomputation of ϕ and also in order to avoid confusion, it seems, therefore, more practical to retain $C = 299776$ and the associated values of ϕ in all computations to be carried out.

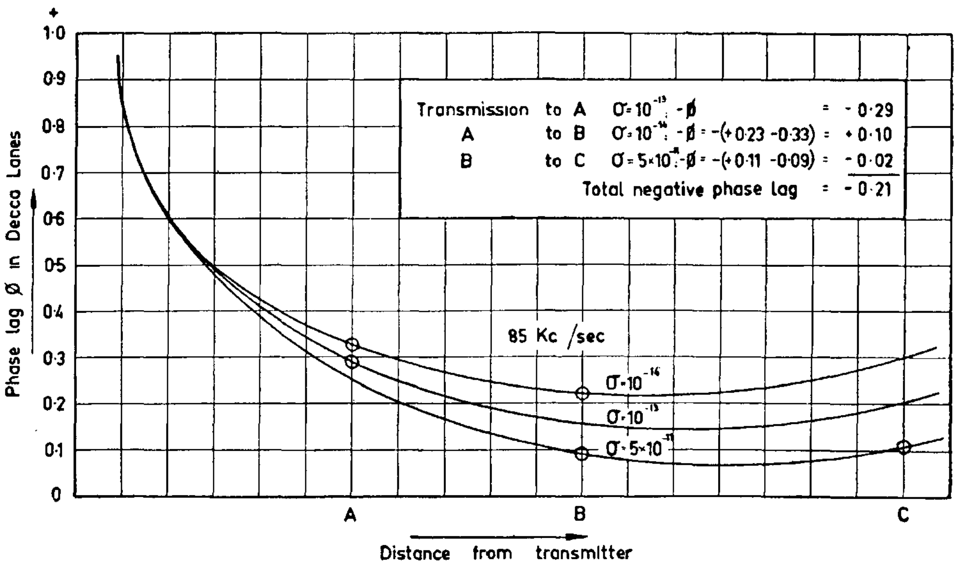

Fig. 2.

Observation 3: In the formulae of Norton and Bremmer, the earth has been taken as a sphere with a radius of 6390 km. Computation shows that the actual (mean) radius of curvature of a geodetic line on the (most unfavourable) ellipsoid never departs more than 0.5 % from this value. A 0.5 % greater or smaller radius, however, affects the length of a terrestrial arc of 500 kilometres only by 1 part in 365,000; this can be regarded as negligible compared with the effect of other sources of errors.

3. *Measuring of distance by means of Decca*

The theoretical number of lanes n^1 on a *baseline* joining Master and Slave is

$$n^1 = \frac{2\,b\,F}{C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

wherein: b = *length of baseline in metres.*

F = *comparison frequency in cycles/sec.*

C = *free-air velocity in metres/sec.* (value to be used in connection with the Decca phase-lag curves $= 299776 \times 10^3$).

n^1 consequently may be computed when b and F are known.

* In the 2-range Decca system, measurements have to be carried out very near to the Master transmitter and a special method has to be used to correct for the large values of ϕ.

Conversely, the length of the baseline b may be computed from known values of n^1 and F by transforming the formula (1) as follows:

$$b = \frac{n^1 C}{2F} \quad \text{.........................(2)}$$

The numbei of lanes n, actually existing on a baseline can be obtained as follows from observations:

At both baseline extensions, the Decca hyperbolic position lines degenerate into straight lines (geodetic lines on the ellipsoid); all along these lines there is, of course, a constant phase difference, which means a constant decometer reading.

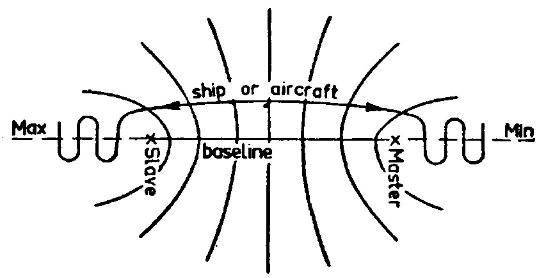

FIG. 3

A Decca receiver is now taken from one baseline extension to the other (fig. 3); the means of transportation may be a ship, aircraft or any other vehicle. When nearing the Slave-extension, the decometer reading will increase until a maximum is reached when crossing the extension. Going beyond, the reading again will decrease. The crossing is repeated a number of times in order to be able to reduce the effect of random errors. Approaching the Master-extension, the reading will decrease and a minimum will be observed when crossing that extension.

The difference between maximum and minimum readings is the number of lanes n, actually existing along the baseline Master-Slave.

In order to be able to compute b by means of formula (2), the maximum and minimum readings as obtained by observation have to be corrected* for phase lags along the path from transmitter to receiver. After applying these corrections, taken from graphs based on Norton's and Bremmer's formulae, the theoretical maxima and minima (for a speed of 299776) are obtained and the theoretical number of lanes n^1, to be used in formula (2), is found by simple substraction. Example of method of correction (fig. 2).

From transmitter to A:

$\sigma = 10^{-13}$ *e.m.u.*; $-\phi =$ —0.29

from A to B:

$\sigma = 10^{-14}$ *e.m.u.*; $-\phi = -(+0.23-0.33) = +0.10$

from B to C:

$\sigma = 5 \times 10^{-11}$ *e.m.u.*; $-\phi = -(+0.11-0.09) = -0.02$

from transmitter to C: $-\phi = -0.21$

* (With negative algebraic sign, because the phase lag ϕ as taken from the graphs, is the correction to be applied to theoretical values.)

In this method of correcting a discontinuity (an abrupt change of phase) is introduced at the boundary of two sections of differing conductivity. Actually the change will possibly take place more gradually, although there are indications from other trials (see para. 5.3) of quite distinct phase changes at or near these boundaries. Taking into account: 1. that only mean values of σ are available; 2. that the boundaries are not always sharply defined lines, and 3. the very good results of the analysis of the Danish trials, it appears that this method of correcting can be accepted as a sufficiently reliable substitute for what is actually happening more gradually.

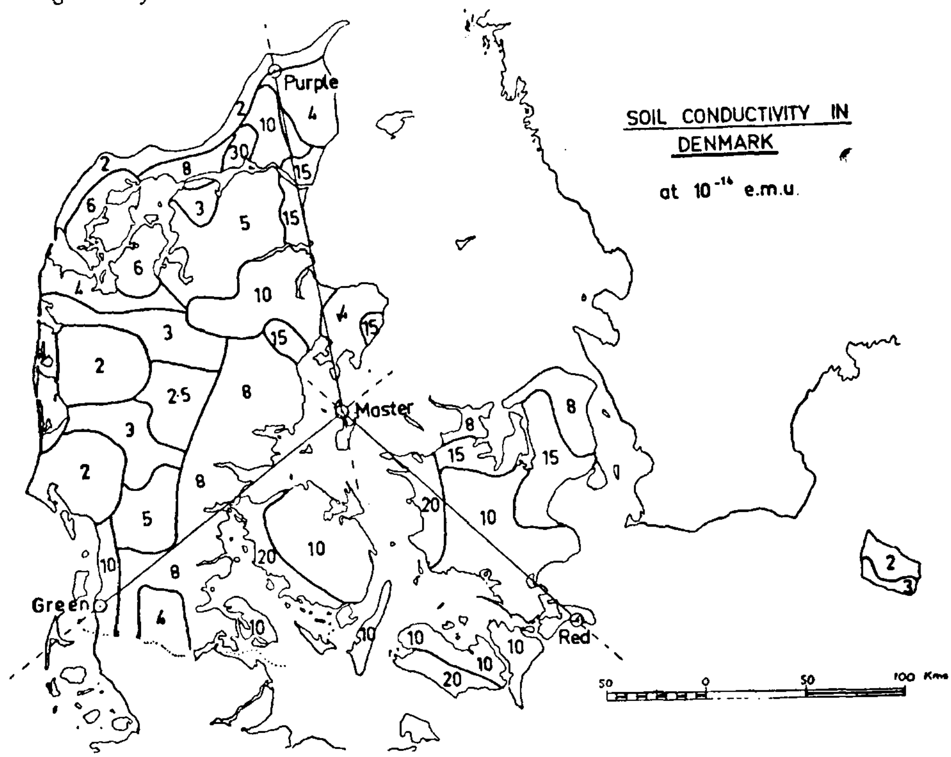

Fig. 4.

4. *Analysis of trials on the Danish Chain*

After the Danish Decca Navigator Chain had been erected for the purpose of safe navigation in the waters surrounding Denmark and on the sea lanes approaching the Kattegat and the Sound, acceptance trials were carried out in April 1949 by the Danish Survey vessel *Heimdal*. Accurate coordinates of the transmitters were known from a very good primary triangulation and the trials were, therefore, not specially intended for distance measurement. They were, however, carried out with such great care, that later it was realized that the observations could be used for that purpose.

Normal navigational receivers were used on board the ship as well as on the monitor stations; in order to reduce small systematic errors, mean values have been used in the analysis of readings on three different receivers. All decometer readings at the baseline extensions were corrected for small shifts of the patterns

— due to fluctuations in the synchronizing of Master and Slaves — as observed at suitably located monitor stations.

In the analysis to be described in this paper, use has been made of graphs of φ against distance for various values of σ, based on Norton's and Bremmer's theory, and computed by the Decca Navigator Company.

Ground conductivity constants σ were made available by the Danish General Post Office (see fig. 4), which also arranged for measuring the exact value of the radiated frequencies.

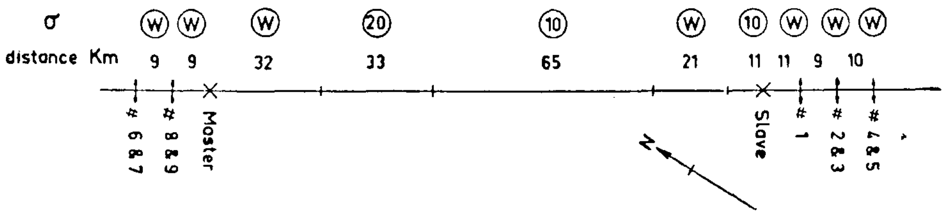

Fig. 5.
Red Baseline.

In fig. 5 the crossing are indicated thus: No. 1, No. 2, etc.; values of σ are indicated thus: (*w*) for water ($\sigma = 5 \times 10^{-11}$ *e.m.u.*), (20) ($= 20 \times 10^{-14}$ *e.m.u.*), etc.; distances are in kilometres as taken from a chart.

A worked out example will be given for the distance Master-Red Slave only; both other distances Master-Green and Master-Purple were treated in the same way and the final results are given below.

DETERMINATION OF DISTANCE MASTER-RED
MASTER SIGNAL

—ϕ correction at Master extension

N° 6 & 7, 18km water	—0.020
N° 8 & 9, 9km water	—0.040

—ϕ correction at Slave extension

32km water	—0.012
33km (20)	—0.055
65km (10)	—0.102
21km water	—0.018
11km (10)	—0.018
	—0.205
N° 1. 11km water	—0.008
	—0.205
N° 1 =	—0.213
N° 2 & 3, 20km water	—0.016
	—0.205
N° 2 & 3 =	—0.221
N° 4 &5, 30km water	—0.025
	—0.205
N° 4 & 5 =	0.230

SLAVE SIGNAL

—φ correction at Master extension

11km (10)	—0.098
21km water	+0.013
65km (10)	—0.097
33km (20)	—0.040
32km water	—0.018
	—0.240
N° 6 & 7, 18km water	—0.014
	—0.240
N° 6 & 7	—0.254
N° 8 & 9, 9km water	—0.007
	—0.240
N° 6 & 7—	0.247

—φ correction at Slave extension

N° 1,	20km water	—0.022
N° 2 & 3,	20km water	—0.012
N° 4 & 5,	30km water	—0.008

Corrections to be applied to observed maxima and minima to arrive at number of lanes n^1 along Red baseline for $V = 299776$ km./sec. n^1 = corrected max. at Slave extension minus corrected minimum at Master extension. Total correction ta baseline extension = Master signal correction minus Slave signal correction.

Maximum *At Slave extensions*			*Minimum* *At Master extensions*		
N° 1	Master signal correction	—0.213	N° 6 & 7	Master signal correction	—0.020
	Slave signal correction	—0.022		Slave signal correction	—0.254
	Total correction	—0.191		Total correction	+0.234
N° 1	Observed maximum ...	—9.507	N° 6	Observed minimum ...	.23.915
	Total correction	—0.191		Total correction	+0.234
N° 1	Corrected maximum ..	..9.316	N° 6	Corrected minimum ..	.00.149
N° 2 & 3	Master signal correction	—0.221	N° 7	Observed minimum ...	.23.907
	Slave signal correction	—0.012		Total correction	+0.234
	Total correction	—0.209	N° 7	Corrected minimum ...	00.141
N° 2	Observed maximum ..	..9.520	N° 8 & 9	Master signal correction	—0.040
	Total correction	—0.209		Slave signal correction	—0.247
N° 2	Corrected maximum ..	..9.311		Total corrections	+0.207
N° 3	Observed maximum ...	..9.510	N° 8	Observed minimum ..	.23.935
	Total correction	—0.209		Total correction	+0.207
N° 3	Corrected maximum ..	..9.301	N° 8	Corrected minimum ..	.00.142
N° 4 & 5	Master signal correction	—0.230	N° 9	Observed minimum ...	.23.947
	Slave signal correction	—0.008		Total correction	+0.207
	Total correction.......	—0.222	N° 9	Corrected minimum ...	.00.154

N° 4	Observed maximum ..	..9.507
	Total correction	—0.222
N° 4	Corrected maximum	..9.285
N° 5	Observed maximum ..	..9.505
	Total correction	—0.222
N° 5	Corrected maximum ..	..9.283

9.3160
9.3110
9.3010
9.2850
9.2830

Mean maximum 9.2992 ±0.0066...4444 (*r.m.s.e.*)

.1490
.1410
.1420
-1540

Mean minimum .1465 ±0.0034... 1130 (*r.m.s.e.*)

Mean maximum 9.2992 ±0.0066...4444

Mean minimum 0.1465 ±0.0034...1130

n[1] = 369.1527 ±0.0075...5574 (*r.m.s.e.*)

$F = 341452 \pm 4c/s$ $C = 299776000 m/s$

$$b = \frac{n^1 C}{2F} \quad \ldots\ldots (2)$$

$$m_b = \sqrt{\left(\frac{C}{2F}\right)^2 m^2_{n^1} + \left(\frac{n^1 C}{2F^2}\right)^2 m^2_F} \quad \ldots\ldots (3)$$

measured by Decca, b=162,047.8±3.49 metre (*r,m.s.e.*)
geodetic distance =162.044.8± ? metre*

Difference=—3.0 metre
Difference= 1 part in 54,015
Difference = 1 *part in* 54,000 *approx.* (RED)

Determination of distance Master-Green

measured by Decca, b=157,118.5±4.98 metre (*r.m.s.e.*)
geodetic distance =157.121.0± ?

Difference= +2.5 metre
Difference= 1 part in 62,848
Difference = 1 *part in* 63,000 *approx.* (GREEN)

Determination of distance Master-Purple

measured by Decca, b=170,659.3±5.98 metre (*r.m.s.e.*)
geodetic distance =170,657±4 ? *

Difference=1.9 metre
Difference=1 part in 89,820
Difference=1 *part in* 90.000 *apprx.* (PURPLE)

* Unknown, but likely to be of the order of 1 metre.

5. *Some conclusions from other trials*

Decca trials carried out during the first few years after World War II, do not — from a point of view of survey applications — show very accurate results and it is the author's opinion that these earlier poor results are mainly responsible for the apparently widely held opinion that Decca under no circumstances can be regarded as a suitable system for measurement of long distances over land. Compared with navigational — as well as survey transmitters and receivers — available at the present time, the equipment in those days was relatively poor and, in addition, knowledge on propagation was limited. These earlier shortcomings explain the unsatisfactory results for this type of precision work.

The main conclusions — very briefly stated — from more recent trials (as far as related to the subject discussed in this paper) are:

1. Radio waves of frequencies around 100 kc/s penetrate into the ground over which they are travelling and, therefore, lose energy. Depth of penetration up to about 200 feet may affect phase velocity where general conductivity is poor. The conductivity iself is mainly dependent on geological structure. Surface soil has little effect on phase velocity, unless it is of very high conductivity (for instance swampy terrain); in this case the effect of the sub-soil is small.

2. From trials in Great Britain (1) a mean value of phase velocity at 127.5 kc/s (Decca Green Slave) has been determined over a path of 177 kilometres of very much changing conductivity ; a mean value of 299230 km/sec. was determined with an accuracy of ± 12 km or 1 part in about 25,000. It was estimated from those trials that, over a homogeneous path of this length and with similar transmission conditions, an accuracy of about ± 3 km/sec. — 1 part in about 100,000 could be obtained.

3. According to (1) there is apparently a *sudden* increase in phase lag as the wave passes from ground of high conductivity to that of low conductivity and a similar decrease in phase lag as it passes in opposite direction.

4. Changes in ground contours along the transmission path of less than 0.3λ (λ is of the order of 3,000 metres) are not likely to affect phase velocity in any serious way. There was no evidence of such effects in the trials described in (1); in this case change in ground level along the path did not exceed 0.1λ.

5. Meteorological conditions do not appear to be very critical at the wavelengths used by Decca. When extreme meteorological conditions are avoided, the phase velocity does not seem to be influenced to any appreciale amount by atmospheric conditions; anyhow, it has until now not been possible to show these effects from observations.

Aiming at accuracies of the order of 1 part in 100,000, however, it seems likely that corrections need to be applied. Further research is desirable.

6. From very accurate measurements on the Swedish Decca Survey Chain (2), Laurila deduced a mean phase velocity over *water* of 299700 ± 23 km/sec. (1 part in about 13,000). The observations, however, were taken mainly for another purpose (position fixing) and were not particularly suitable for a determination of the propagation speed.

6. *Factors affecting accuracy*

A discussion on this subject could go into much more detail, but in this paper the main points only will be mentioned:

1. Throughout the trials on the Danish chain, normal navigational equipment (1948 design) has been used. Decometers have certain systematic errors which may amount to something of the order of 0.03 lane as a maximum; it is believed that this type of error has been eliminated (at any rate to a considerable degree), because mean values of three different decometers have been used in the analysis and because each extension was crossed three or four times at different distances from the transmitter.

2. The set-up of the programme of acceptance trials of this Decca Chain was not especially intended for accurate distance determination. In particular, the number of crossings at the baseline extensions was small.

3. The phase-lag curves, used for the computation of ϕ, are on a comparatively small scale. By independently scaling off three times, however, it is believed that an accuracy of the order of ± 0.002 lanes has been reached.

4. Accuracy is possibly influenced in an unfavourable way by the fact that the values of σ have not been determined for the Decca frequencies of around 100 kc/s, but for nearby frequencies. From observations in other countries, however, it can be shown, that it is only very slightly influenced by the frequency of transmission.

On the other hand, it should be borne in mind that the conditions of propagation along the Danish baselines and their extensions can be regarded as reasonably favourable, both with respect to changes in conductivity and the topography (height differences not exceeding 0.1λ).

5. Complete information is not available to the author, but it is believed that the geodetic distances as used for the comparison in para. 4, are accurate to about 1 part in 150,000.

6. All three root mean square errors as given in para. 4, are larger than the differences between Decca — and geodetic distances. It is believed that this may be explained by the fact that navigational receivers have been used. This will have resulted in comparatively large differences between individual determinations of maximum and minimum readings at the baseline extensions with as a result, comparatively large root mean square errors.

7. *Possible improvements*

As in para. 6, a discussion on this subject could go into much detail; in this paper the main points only will be briefly mentioned.

1. For geodetic work, survey equipment of the latest design should be used. Among other improvements, the systematic errors in the decometers can thus be reduced; such errors should also be determined and applied as corrections to the readings. According to reference (2) and other available information, systematic errors in decometers can thus be reduced to 0.008 lane (or possibly less).

2. The number of crossings should be increased to at least ten at each of the extensions,

3. Graphs of φ can be constructed at a larger scale in order to increase accuracy of scaling off.

4. More accurate values of σ are likely to be obtainable only at considerable troubles and cost, which would seriously limit the practical value of the method of measuring distances by Decca.

5. There is no doubt that with survey equipment the root mean square values in the observed Decca distances would have been in closer agreement with the differences between Decca, and geodetic distances.

8. *Conclusions*

1. Distances of 162, 157 and 171 kilometres — mainly over land — have been measured by Decca, using comparatively crude equipment, with an accuracy of 1 part in 54,000, 1 part in 63,000 and 1 part in 90,000, respective to known geodetic distances. The project was carried out by the surveying vessel *Heimdal* in eight working days, but this could be reduced to just as many hours when flying round the baselines in a plane.

2. There is no absolute guarantee that these figures can be regarded as representative under all circumstances.

Based on the results of these Danish, as well as on other trials,* it is, however, believed that any distance over land can be measured by Decca with an accuracy of at least 1 part in 50,000 and possibly better, provided the ground over which the waves are travelling is not too rugged, its electrical conductivity constants are known with reasonable accuracy and the conductivity is not too poor nor changing to much from point to point.

3. The trials carried out until now, should be regarded as most valuable indications as to the degree of accuracy of which Decca is capable for the purpose of distance measurement. Further trials should, however, be carried out to confirm the conclusions of this paper.

4. Survey equipment of the latest design should be used in all survey applications.

5. As the theory, applied in this analysis, conforms so well with the facts, there can be no doubt that it can be applied with still more confidence under the much more favourable circumstances when propagation takes place over flat ground of homogeneous conductivity. Especially favourable conditions are swampy In the latter case, and making use of survey equipment, it does not seem too optimistic to expect accuracies of the order of 1 part in 100,000 in a distance of a couple of hundred kilometres.

6. Except over a sea path, information on ground conductivity is essential when any great accuracy is required. In many countries, the national General Post Office will have this information available, as it is essential also for radio broadcasting and radio communication purposes. Where not available, values of σ need be computed from geological information and measurement of field strength of existing transmitters. The amount of available information will determine the accuracy of the σ — values and, therefore, will be one of the main limiting factors in Decca distance measurements over land.

Under circumstances where information on ground conductivity is completely lacking, Decca distance measurement should be limited to propagation paths over water or — to a somewhat limited degree of accuracy — over swampy terrain.

9. *Acknowledgements*

The material for this analysis has been kindly made available to the author by the Danish Hydrographer Kommodore P. Jensen and by the Danish General Post Office, while graphs of phase lags, based on Norton's and Bremmer's formulae, were kindly supplied by the Decca Navigator Company, London, and computed by Mr. Schneider. The utmost care with which the actual observations were carried out by Captain (now Kommodore) Axel Schmidt and his officers, are responsible for the excellent results. Valuable information also was supplied by Mr. Ole Moller from the Danish Hydrographic Office and by Mr. Dorph Petersen from Decca Navigator A/S, Denmark.

* See: (1) and (2).

REFERENCES

(1) The measurement of the phase velocity of ground-wave propagation at low frequencies over a land path, by B. G. Pressey. G. E. Ashwell and C. S. Fowler; Proc. of the Institution of Electrical Engineers, Vol. 100, part III, No. 64, March 1953.

(2) On the application of barometric air levelling and Decca radio position fixing in the formation of Geodetic networks for small scale maps, by Simo Laurila; thesis for the degree of doctor in technology; Helsinki, March 1953.

Both references give a fairly complete list of literature.