USE OF THE DECCA NAVIGATOR SURVEY SYSTEM IN NEW GUINEA FOR HYDROGRAPHY AND AS A GEODETIC FRAMEWORK

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I. — INTRODUCTION AND GENERAL REMARKS

1.1. In 1955 it was decided to survey the hitherto only very sketchily charted Arafoera Sea between the south coast of the Netherlands part of New Guinea and Northern Australia. This survey will take many years and is to be regarded as part of the Government's development plans for the island. The hydrographic survey includes the sea area as well as the rivers as far inland as they are navigable by small craft, and is to be alternately carried out by one of the two survey vessels H.N.M.S. *Snellius* and her sistership H.N.M.S. *Luymes*, both from the Hydrographic Department of the Royal Netherlands Navy.

1.2. The *sea area* to be surveyed, shown in fig. 1, is some 300 000 square kilometres (120 000 sq. st. mi.). Short-cut shipping routes from the Far East and the Philippines via Torres Strait to harbours on the east coast of Australia would lead through the Arafoera Sea, but most ships avoid the area and make considerable detours because of the present lack of reliable nautical charts.

The main reason why a hydrographic survey has not been undertaken so far is the difficulty of sufficiently accurate position fixing in the sea area, 95 % of which is out of sight of land. Very broadly speaking, hydrographic charting consists of running lines of (echo-) sounding, parallel to each other at a mutual distance such that it is very unlikely that existing dangers to shipping will escape discovery; depending on the geological formation of the sea-bottom this distance varies between some 50 and 2 000 metres. Coast lines, entrances to rivers and harbours have to be included in the survey as well as the soundings in the open sea.

An essential foundation for this work, not least from the economic standpoint, is that the geodetic position fixing of the lines of soundings should be of good accuracy, otherwise overlaps or gaps cannot be avoided. It would be possible — though extremely difficult and costly in New Guinea — to set up a terrestrial triangulation along the coast, but for the 95 % of the area that is out of sight of land this would be valueless, and the position fixing would have to be based either on a « triangulated » network of anchored floating beacons or on celestial position fixing. It needs no detailed explanation to show that neither of the latter two methods can give reasonable accuracy. The geodetic accuracy in a framework of floating marks will rapidly deteriorate after only a few triangles, because the beacons have a large turning circle around their anchorage. The accuracy of celestial position fixing at sea cannot be expected to be much better than about 1 nautical mile or roughly 2 kilometres and is therefore quite insufficient for fixing the parallel lines of soundings.

Until the advent of electronic position fixing systems these floating beacons and/or celestial observations were the only means available when out of sight of land. Although unsatisfactory, they were acceptable, because a ship, navigating on the charts, could only fix her position with even lower accuracy. Nowadays, however, shipping in some areas has, and in other areas in the near future may have, accurate radio position fixing systems at its disposal and a modern nautical chart should fulfil the requirement that its geometrical accuracy is better than that of the ships' position fixing. Fortunately the principles of some of the radio *navigation systems* allow of very considerable refinement in transmitters as well as in receivers and therefore in their improved version can be used as *survey systems*. Such survey systems can now be regarded as indispensable for many types of survey work in undeveloped countries, at sea as well as on land.

1.3. In addition to the above-mentioned large sea area of 300 000 sq. km., the many navigable rivers in a *land area* of 250 000 sq. km. had to be included in the hydrographic survey. This makes up a total of 550 000 sq. km. (Great Britain and Northern Ireland cover an area of roughly 250 000 sq. km.).

There is no existing terrestrial triangulation and it would be practically impossible to measure a geodetic network of even 2nd or 3rd order accuracy in this flat and swampy part of New Guinea. Here also an electronic survey system is the only practical answer to the problem.

1.4. Nowadays there is a choice between several systems of an accuracy suitable for certain types of survey work. They all have their limitations and some suit certain requirements better than others. They are all expensive to buy as well as to maintain and therefore the definite choice of a system will always have to be a compromise between the many, and often conflicting, requirements of the surveyor.

For the New Guinea sea and land survey — and eventually also for an aerial survey — a *Decca Survey Chain* of the latest type was considered to be the most suitable equipment and was purchased.

In this paper the principles of the system are assumed to be known; they have been described in numerous publications and detailed information, including weight and dimensions of equipment, are given in the Decca « Survey Manual ».

1.5. The accuracy required in an undeveloped country like New Guinea is not of first order as this expression is normally understood in geodesy. Extremely high accuracy would not serve any practical purpose, among other reasons because the charts will be *published* on a small scale. The accuracy achieved in actual practice proved to be more than sufficient for the purpose and will be discussed in detail in section 16.

Attention is drawn to the very important fact that, although a single Decca position in itself is not of first order accuracy, this can be accepted because there is *no accumulation of errors* in the position fixing; it is for this reason that errors that are large in comparison to those in terrestrial measurements can be tolerated.

1.6. The range of Decca survey transmitters for accurate work is about 400 kilometres and it is therefore completely out of the question to cover the

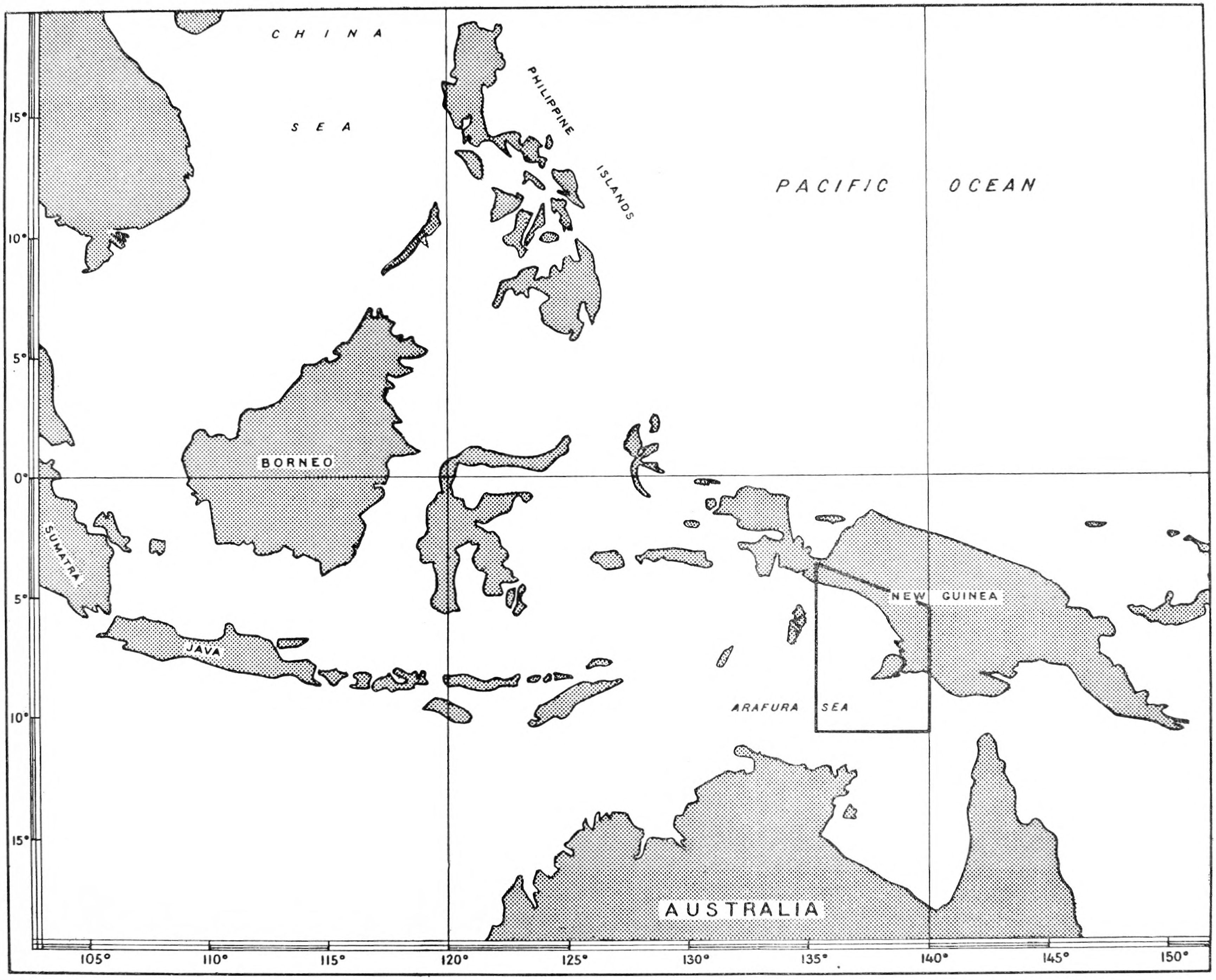

C H I N A
S E A
PHILIPPINE
ISLANDS
PACIFIC
OCEAN
BORNEO
SUMATRA
JAVA
NEW GUINEA
ARAFURA SEA
AUSTRALIA
15°
10°
5°
0°
5°
10°
15°
105°
110°
115°
120°
125°
130°
135°
140°
145°
150°

Fig. 1.

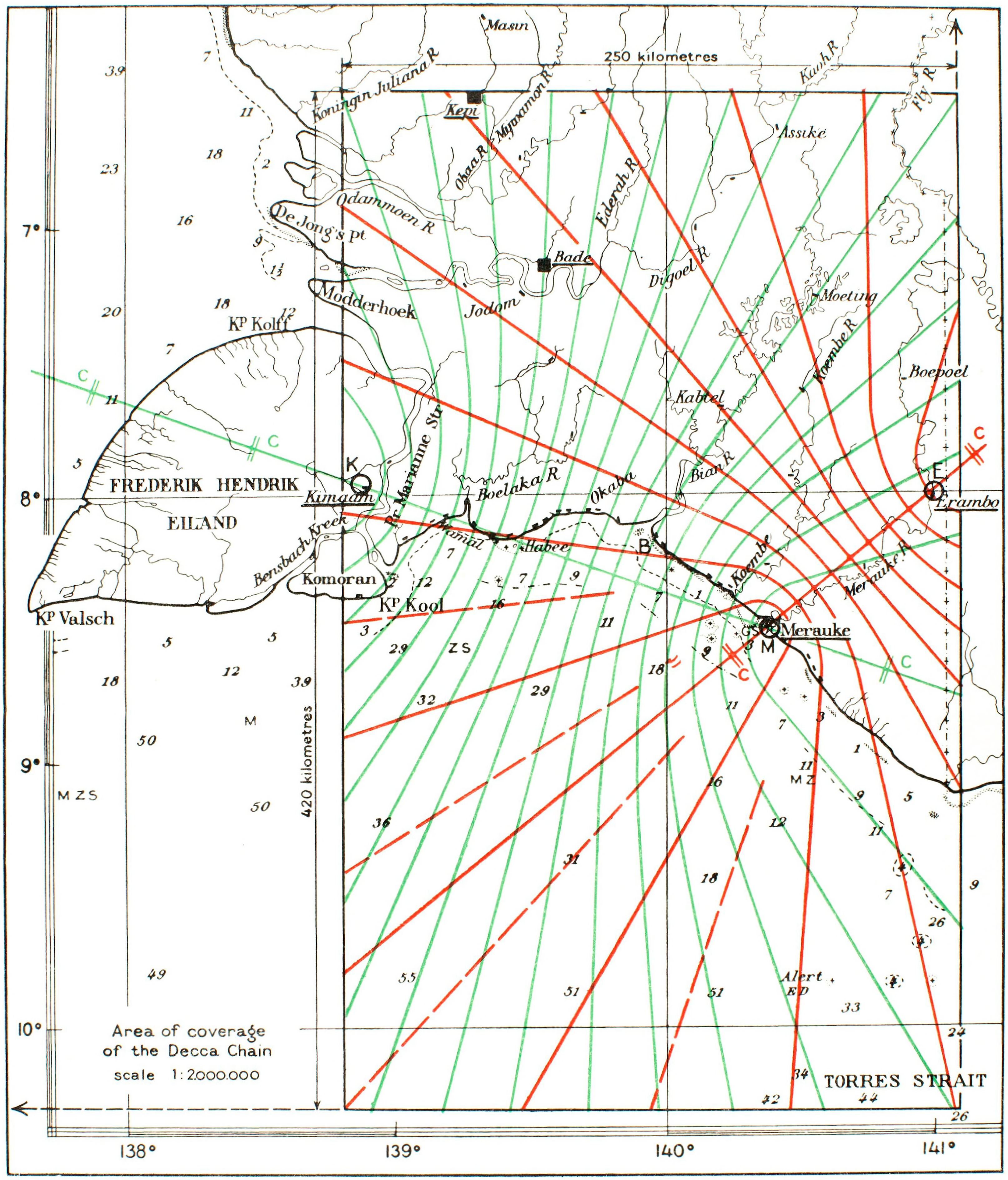

250 kilometres
420 kilometres
Area of coverage
of the Decca Chain
scale 1: 2.000.000
Masin
Kepi
Koningin Juliana R
Mapamon R
Obaa R
Odammoen R
De Jong's pt
Bade
Ederah R
Digoel R
Jodom
Modderhoek
Kp Kolff
Assike
Kaoh R
Fly R
Moeting
Koembe R
Boepoel
Kabtel
Bian R
FREDERIK HENDRIK
EILAND
K
Kimaam
Pr. Marianne Str
Boelaka R
Okaba
Kamal
Habee
B
Bensbach Kreek
Komoran
Kp Kool
Kp Valsch
Koembe
Merauke
M
GS
E
Erambo
Merauke R
C
ZS
MZ
M
MZS
Alert
ED
TORRES STRAIT
7°
8°
9°
10°
138°
139°
140°
141°

Fig. 2.

enormous area of 550 000 square kilometres (220 000 sq. st. mi.) by one single set-up of the three transmitters (Master, Red and Green (see fig. 1). The chain however is of the transportable type and the transmitters will be moved to new sites as soon as the first area of coverage has been surveyed.

1.7. The complete equipment, including motor generators and prefabricated houses, arrived in New Guinea at the end of 1955 and setting-up of the stations under the supervision of the author was started in January 1956. The location of the stations and the area of coverage may be seen in fig. 2.

1.8. Although one case is known where the Decca Survey System has been used without ground control, it is for the first time that reliable information could be obtained as to the actual accuracy under conditions when no terrestrial triangulation is available to tie-in the position of the transmitters.

In this paper the many problems that arose will be discussed in the sequence of the various stages in which the setting-up and pattern computation was — and under similar conditions should be — carried out.

2. — RECONNAISSANCE AND BUILDING OF STATIONS

2.1. Although from the point of view of radio-wave propagation the requirements for siting Decca stations are not at all critical, certain conditions are more favourable than others; moist terrain, for example, is preferable to dry sandy ground because the latter absorbs more of the radiated energy, and the stations should be well clear of overhead lines and high metal structures.

Operational requirements dictate that the unloading and installation of the equipment should not be too difficult. The stations should be reasonably accessible at any time for purposes of personnel relief, medical help, maintenance, food supply, etc. In densely inhabited and developed areas this would as a rule present few problems, but New Guinea's south-east coast is swampy terrain with a very small population and nowhere are there facilities such as electricity, gas or even good drinking-water. Some areas even had to be ruled out on account of headhunters and cannibals!

In such remote and undeveloped country, the correct choice of the sites is a very important one, because the uninterrupted functioning of the chain is to a high degree dependent on it.

2.2. Sites were planned beforehand in Holland, based on the available information, but only one — Merauke, the local district « town » (M in fig. 2) — proved to be suitable. The complete equipment for the three stations had been sent there and put in store. After arrival of the survey vessel, work was started at the Master station, 3 miles from Merauke. Transport to the site (near the beach) was by no means easy and transport facilities were limited to a small truck, an ox-cart and the ship's Jeep; a tropical rainstorm of half-an-hour's duration would make the road impassable for at least the next 24 hours. After clearing the site, the 180-foot mast was set up within two working days, but erecting the prefabricated bungalows, station huts and motor generators took three weeks, mainly because transport difficulties and lack of local labour resulted in practically all this work having to be done by the ship's crew.

2.3. The other two sites, as planned beforehand, were to have been on small islands. As soon as work had started on the Master, these places were reconnoitred from the air, but both proved to be unsuitable as they were surrounded by uncharted coral reefs. Also for various reasons they seemed to offer no guarantee of permanent accessibility. In three days of aerial reconnaissance over thousands of square miles, only four possible sites could be located, two of them being barely acceptable on the grounds of insufficient angle of cut of the hyperbolic patterns. One of the two remaining was a village called Kimaan (K in fig. 2) and the other a small settlement known as Erambo (E). A study of Erambo from the air left some doubt as to possible inundation in the wet season, but the District Officers at Merauke could give no conclusive information on this. It was therefore decided first to reconnoitre the place by means of a shallow-draft landing craft, including the river all the way from Merauke to Erambo; along the winding river this distance effectively totalled 230 km. As the river was uncharted and had many dead trees under water, this was an experience in itself and took two days. Erambo was found to contain 50 natives and no Europeans, and proved to be excellently situated on a small hill some 3 metres above the highest known flood level.

2.4. Local transport and labour facilities did not permit more than one station to be erected at a time and therefore the building of the Red Slave at Erambo could not be started until the Master at Merauke was complete. Here also, the construction of bungalows, station-huts, etc., took most of the time, but the station was operational within three weeks including the time involved in transport.

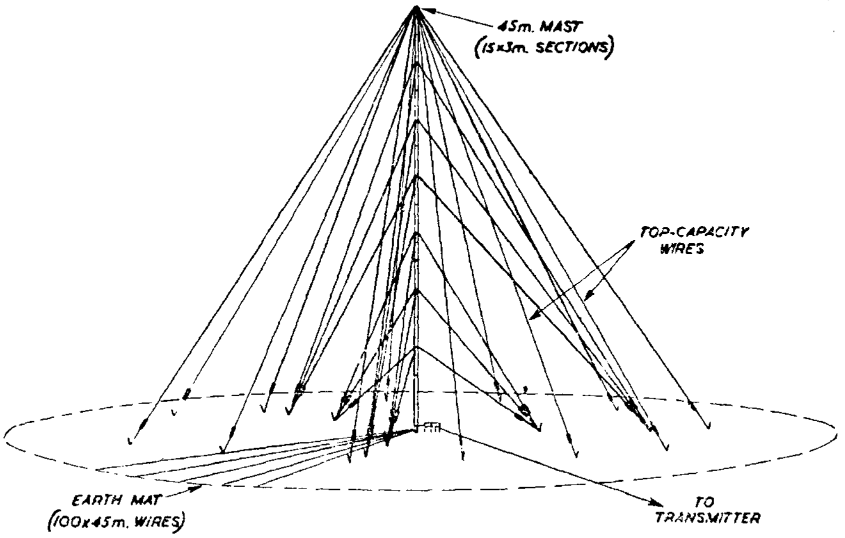
The Green Slave at Kimaan required a similar period. From the local European missionary we knew beforehand that this site would at least be usable. The main difficulty proved to be the access to the place through the narrow creek which, because of many dead trees under water, could be navigated only at high tide. There was a « road » half a mile in length along which it took 50 coolies a whole day to bring up one motor generator. The road had a few « bridges » but these broke down under our weight and it took time for the ship's crew to repair them.

In more developed countries it might take a week to put up a complete Decca chain of the type used, but under the conditions encountered we felt no reason to complain about the 2 ½ months it took to get the New Guinea chain into full operation.

3. — FIELD STRENGTH MEASUREMENTS

3.1. New Guinea is one of the countries with the world's highest radio noise-level and it is therefore to be expected that the range at which Decca receivers will get sufficient signal strength for reliable operation will be smaller than in higher latitudes, for transmitters radiating the same amount of energy.

3.2. The basic design of the Decca receiver enables it to operate under conditions of very low signal-to-noise ratio; the RF bandwidth is only ± 30 cycles at the half-power points and the internal noise in the set itself is low. However, in order to ensure maximum stability of operation at long ranges, extra mast sections amounting to 30 feet were added to the transmitting antenna at the master station, bringing the total height to 180 feet. The antenna-ground system is shown in fig. 3; an efficient ground mat is essential at the Decca frequencies and this consisted of 100 radial copper wires 150 feet in length.



SKETCH OF 45m. TRANSMITTING AERIAL/EARTH SYSTEM.

Fig. 3.

The enlarged master antenna gave an estimated 18 watts radiated power, representing an increase of some 20 %. The slave stations radiated approximately 15 watts. At each station the transmitter delivered 600 watts into the aerial, the relatively low radiated power being the result of the small size of the antenna in relation to the transmitted wavelength (of the order of 3 000 metres for Decca).

3.3. On theoretical considerations the predicted maximum range was sufficient, but operational experience with Decca in the tropics was far too limited for accurate prediction of the number of kilometres at which the received signal strength would be sufficient to ensure reliable operation.

As soon as the Master and the Red Slave were operating, it was therefore considered necessary to make field-strength measurements. A prime consideration was to make absolutely sure that the Green Slave could be very accurately phase-locked to the Master over a distance of 170 km, as well as to find out the maximum range of reliable operation.

These measurements were carried out by the ship at hourly intervals along the route and up to maximum distance as indicated in fig. 4. As this survey chain is intended for day-time use only, the field strength measurements were carried out during daylight hours and the ship was anchored at night. Referring to fig. 5, the small spread of the individual observations with respect to the smooth curves may be regarded as an indication of the reliability of the measurements.

It was concluded that accurate locking over 170 km would be absolutely guaranteed. As to reliable functioning of the Decca receiver, it is usually supposed that the signal strength should not be less than 10 or 15 microvolts. Signal strength alone, however, is not the only determining factor because of atmospheric and other sources of noise; from a practical point of view, valuable information about the combined effect of all factors can be obtained even from a couple of hours' observations of the pattern stability — « monitoring » — at a fixed location. The anchored ship was used for this.

From the observations, it could be concluded that signal-strength, or rather signal-to-noise ratio, would be sufficient (in daytime) up to at least 400 km from a transmitter. Hence it was considered that the area outlined in fig. 2 (250 × 420 km) could safely be adopted as the coverage of the chain for survey purposes.

3.4. The measurements proved that the signal-to-noise ratio and the maximum range under these severe noise conditions were far better than could be expected from existing information.

3.5. The observations plotted in fig. 6 suggest that there is some diurnal variation in field strength.

4. — GENERAL CONSIDERATIONS AS TO THE RELATION BETWEEN RADIATED AND CHART PATTERNS

4.1. The Slave transmissions are phase-locked to those of the Master and — neglecting variations in propagation characteristics — their combined transmissions result in a pattern that has a stable position in space. At sea-level, or any level parallel to it, this gives rise to a stable pattern of hyperbolic position lines (lines of equal phase difference), which in an idealized form mathematically are spheroidal hyperbolae. The Decca receiver measures its position with respect to these invisible lines and displays the result numerically on the decometers. The combination of a Master and two suitably-located Slaves produces two intersecting patterns of hyperbolic position lines and thus enables the position of the Decca receiver relative to the transmitters to be determined.

The practical problem is to convert the decometer readings — or hyperbolic coordinates — into chart coordinates. An obvious, and therefore the usual, way is to compute the position of the radiated patterns (spheroidal hyperbolae) in coordinates of latitude ϕ and longitude λ or Cartesian coordinates X and Y and plot these coordinates in the desired chart projection.

The procedure when actually surveying with Decca, therefore, is to plot the decometer readings in the hyperbolic chart patterns and read the desired coordinates ϕ and λ or X and Y on the graticule or grid of the chart. In fact this method is a graphical conversion of hyperbolic into geographical or rectangular coordinates.

4.2. The requirement obviously is that a chart pattern should be the correct representation of the radiated pattern (in this case at sea-level). *Any method of pattern computation should aim at achieving this equality.*

To this end, it is in the first place necessary that the computed and radiated patterns contain an exactly equal number of lanes; fortunately this number of physically existing lanes can be observed by the procedure of lane-counting to be discussed in section 7.

To make this number of lanes fit into a Master-to-Slave baseline, the second step is either (a) to compute the propagation speed from the number of lanes and the terrestrially known length of the baseline and to use these data for pattern

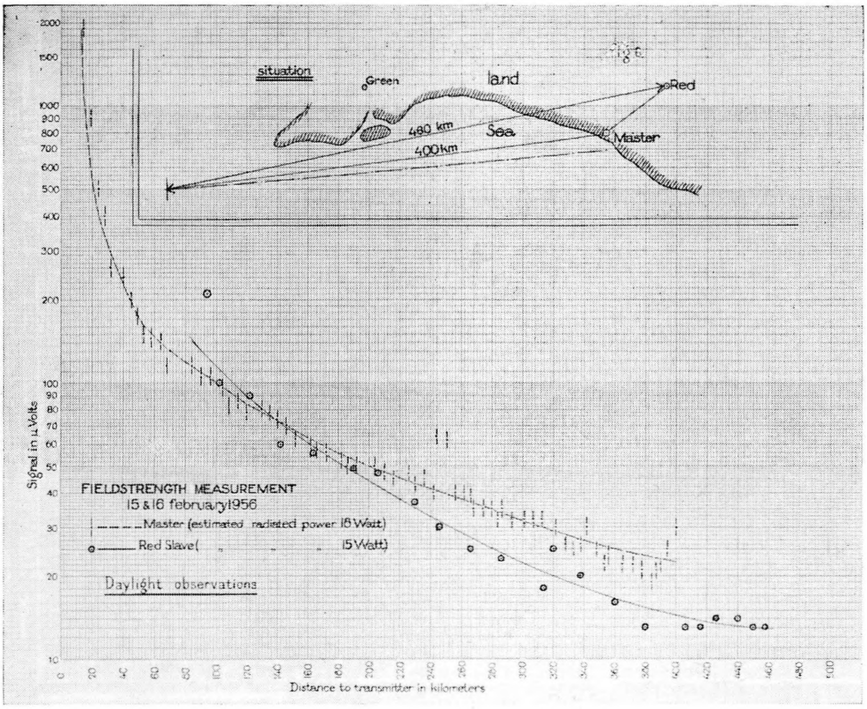


Fig. 4 and 5.

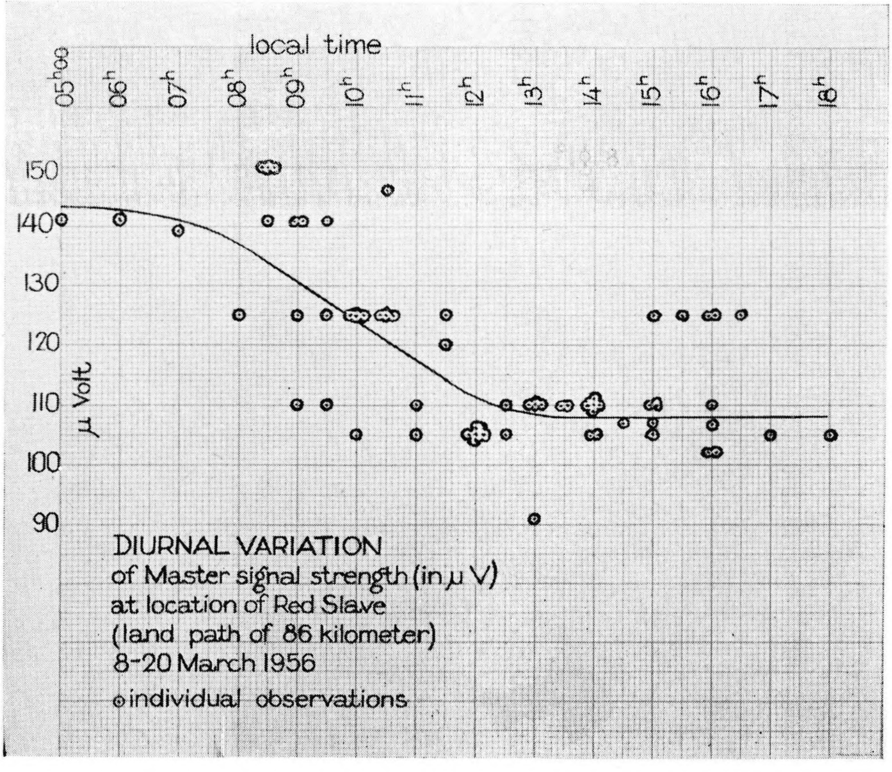


Fig. 6.

computation or (b) to derive the length of the baseline from the counted number of lanes and an adopted value of the propagation speed. In both cases the computed and radiated patterns will agree.

In the first case (a), the terrestrial coordinates of the two transmitters must be known and the computed chart pattern will be correct as to scale and orientation, provided of course that the terrestrial triangulation is correct.

In case (b) — no existing triangulation — the computed baseline and therefore also the scale of the chart in which the computed pattern is plotted, will be just as much in error as the error in the adopted value of the propagation speed. Also, in this case additional information is necessary to determine the azimuth of the baseline.

4.3. The relation between the number of lanes, the length of the baseline, the propagation speed and the radio frequency may be seen from the following formula:

$$n = \frac{2bF}{V} \quad \text{..........} \quad (1)$$

wherein n = number of lanes.
b = length of baseline.
F = (comparison) frequency.
V = propagation speed.

n can be obtained from observations (lane-count).

F is a known quantity.

V — being dependent on circumstances — is only approximately known.

In order now to make n in the computed pattern agree with the observed number, either b has to be known and V to be computed from the formula, or a value of V is adopted and then b can be computed from the formula.

> In some publications b as well as V are adopted and used in the pattern computation. This is of course a wrong procedure, because n in the computed pattern will seldom be equal to the actually existing number of lanes and there will be unnecessarily large discrepancies between computed and radiated patterns. This in turn will lead to « unexplainable » pattern-corrections (see section 14), which in the main will have nothing to do with anomalies in propagation, but are largely caused by wrong assumptions in the pattern computation.
>
> *Note:* In cases where triangulation is unreliable or non-existent, one should be very careful not to mix up contradicting data. In this case, one and only one baselength or propagation speed should be adopted and all other information in the second pattern must be derived therefrom and from Decca measurements as will be explained in the following sections. This is the *only way* to get two intersecting chart patterns in agreement with the radiated patterns.

5. — GENERAL PLAN FOR ESTABLISHING A GEODETIC FRAMEWORK FOR THE CHAIN

5.1. It has already been mentioned that no terrestrial triangulation existed in the area and that setting-up and measuring one would have been out of the question. In one way or another it was therefore necessary to establish a geodetic framework, the method being such that agreement between chart and radiated patterns is maintained. That means there should be conformity between the two sets of hyperbolic lattices, but not necessarily congruency, because the latter is only a question of scale of the Decca chart.

5.2. The problem was solved as follows: —

5.2.1. Astronomical observations were made at M and K (see fig. 2) and the spheroidal length and azimuth of the Green baseline ($=b_G$) were computed (international spheroid) from the geographical coordinates φ and λ of these two astrostations. *This was adopted as a provisional length and azimuth of the Green baseline and the framework is solely based thereupon and on Decca measurements* to be mentioned later in this section.

5.2.2. A mean propagation speed V_m along the mixed path MK (67 km land and 111 km sea) was computed from b_G and $_G$ as in formula (1), section 4.

5.2.3. Based on a simplification of the Norton-Bremmer theory of radio-wave propagation, a diagram was constructed giving the ratio of the propagation speed over sea V_s and over land V_l. This ratio was used to split up V_m into two speeds V_s and V_l.

5.2.4. As the Red baseline ME is entirely over land and as this land may be considered to have the same electromagnetic conductivity σ as the land part of MK, the value of V_l was used to compute the spheroidal distance $ME=b_R$ from the counted number of Red lanes n_R; formula (1).

5.2.5. Now, with the combination MK transmitting and the Red Slave shut off, the Green lane number was observed by means of a receiver at E. Thereafter the Red lane number was observed in the same way at K.

From these Decca observations the difference in azimuth between the two baselines can be computed in a manner to be described in section 11.

As the azimuth of MK is known — or anyhow provisionally adopted — from the two astrostations, the provisional geographic coordinates φ and λ of E can be computed from the now known spheroidal length and azimuth of the Red baseline.

5.2.6. The framework of the three transmitters thus determined forms a *self-consistent* system of coordinates, having been measured with one and the same yardstick, being the (provisional) values of the propagation speeds V_s and V_l. This geodetic framework can now be used to compute both the Red and Green chart patterns and they will be in conformity with the patterns actually radiated.

The Red pattern was computed with the speed V_l and for the Green pattern V_m was used.

Apart from errors in the adopted ratio $\frac{V_s}{V_l}$ and supposing equal ground conductivity everywhere in the land area, the only possible remaining error in the computed Decca chart now is one of scale and azimuthal orientation, resulting from eventual errors in the astro-coordinates of M and K due to unknown differences in plumbline deflection at these two stations. Control as to absolute scale and azimuth was established as follows: —

5.2.7. Decca coordinates were observed at B (see fig. 2) at a distance of 61 km from M and the spheroidal distance and azimuth MB were computed from the adopted coordinates and constants; this distance and azimuth were also computed from a first-order-accuracy traverse MB along a sandy beach.

The difference between the two proved to be negligible. Had it been significant, it could have been used to correct the scale and azimuth of the Decca charts. A recomputation of the patterns would not have been necessary and the easiest way to take this correction into account would have been to change the *graticule* on the Decca charts.

5.3. An obvious advantage of this method of just changing the chart's graticule (and of course also the original scale value as given in the title of the chart) is that pattern computation need not wait for the scale and azimuth control. For economic reasons this is considered very important, because it is always desirable to start pattern computation and surveying as soon as the chain is operating and the necessary measurements, such as lane counting, have been made.

6. — ASTRONOMICAL OBSERVATIONS AND PROVISIONAL SPHEROIDAL LENGTH AND AZIMUTH OF THE GREEN BASELINE

6.1. The method of astronomical observation and computation is that described by Professor Roelofs in (1). The instruments used were a Wild theodolite T2 and a Wild chronograph. WWVH (Hawaii) precision time signals were observed at intervals of about 2 hours.

The results were as follows:

Master (Merauke = M)	$\phi = 08^\circ 30' 22''.37$ S	$\pm 1''.3$ standard error
(32 stars)	$\lambda = 140^\circ 22' 33''.05$ E	$\pm 1''.2$ standard error
Green (Kimaan = K)	$\phi = 07^\circ 59' 23''.82$ S	$\pm 1''.5$ standard error
(28 stars)	$\lambda = 138^\circ 50' 44''.02$ E	$\pm 1''.4$ standard error

Computed on the international spheroid (Jordan formulae):

$$MK = b_G = 178\,011.86 \text{ metres}$$

$$\alpha_{MK} = 288^\circ\ 35'\ 51''.24 \quad (\alpha_{KM} = 108^\circ\ 49'\ 01''.62)$$

6.2. Astronomical observations were carried out also at the Red Slave site at Erambo.

Red (Erambo = E)	$\phi = 08^\circ 00' 35''.92$ S	$\pm 1''.6$ standard error
(96 stars)	$\lambda = 140^\circ 58' 44''.48$ E	$\pm 1''.4$ standard error

These coordinates of E were *not used* in the pattern computations because that would have introduced inconsistencies in the geodetic framework due to possible relative plumbline deflections.

The geographical coordinates of the Red Slave, computed from the length of the Red baseline (section 9) and its azimuth (section 11) are:—

Red	$\phi = 08^\circ 00' 37''.58$ S
	$\lambda = 140^\circ 58' 57''.08$ E

which would result in a plumbline deflection relative to that at the Master of 1".66 in latitude and 12".90 in longitude.

On the basis of the small amount of information available, oil geologists working in the area felt that the magnitude as well as the direction of these relative deflections was of the order that would have been expected. As a matter of fact they were not surprised that the first order traverse (see section 15) indicated no measurable relative plumbline deflection between Master and Green Slave.

7. — COUNTING THE NUMBER OF LANES AND ADJUSTING THE PHASING OF THE STATIONS

7.1. The transmissions from M and S (Master and Slave) in fig. 7 are automatically locked in phase by means of the control circuits at the Slave station. In addition, the position-line patterns so produced are monitored by means of a receiver established at a fixed point, in this instance located for administrative reasons at the Master station site. Operation of the monitor close to the Master is made possible by modifications recently incorporated in the survey receivers, a minimum transmitter/monitor spacing of 10 km having been necessary on earlier surveys.

The decometers are integrating meters (like a gas or electricity meter) and they « count » in a positive direction when the receiver is moved in the direction from M to S, the movement of the meter being reversed when travelling in the opposite direction.

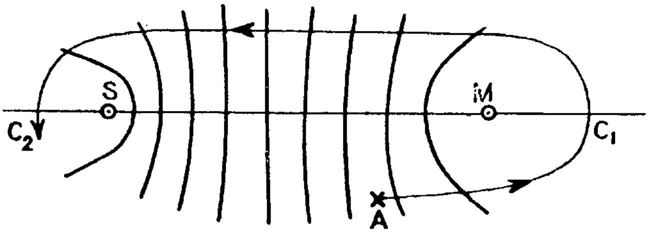


Fig. 7.

Starting from an arbitrary and unknown point A with an arbitrary decometer setting and moving in the direction of the arrow, the reading will decrease until a point C_1, anywhere along the Master-extension of the baseline is reached; beyond C_1 the reading will increase and later decrease again after C_2 has been reached somewhere along the Slave-extension.

The difference between the maximum reading somewhere along the Slave-extension and the minimum at some point along the Master-extension, is the number of lanes, *physically existing* between the two stations.

In order to avoid purturbing effects of the induction field near a transmitter, the baseline crossings should preferably not be nearer to a transmitter than about 5 kilometres. (Corrections can, in fact, be applied for a shorter distance.)

Although in practical use readings are taken to the nearest 0.01 lane only, the reading-accuracy of survey decometers is 0.002 lane. Systematic errors can be corrected for in survey decometers to an accuracy of 0.002 lane.

Example: maximum = +318.358; minimum = —0.042; number of lanes n = 318.400

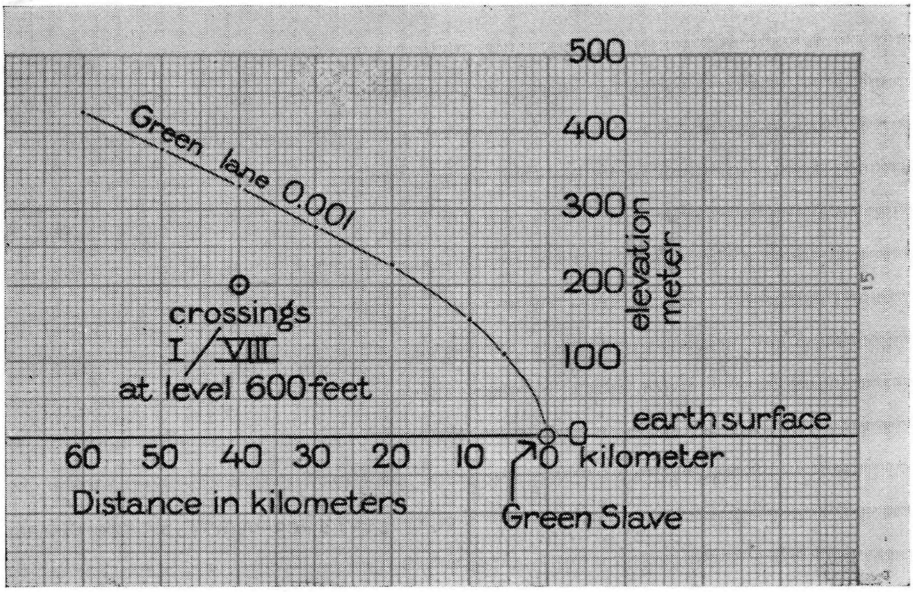

500
400
300
200
100
0
elevation
meter
Green lane 0.001
crossings
I / VIII
at level 600 feet
earth surface
60 50 40 30 20 10 0 kilometer
Distance in kilometers
Green Slave

Fig. 8.

7.2. Because it simplifies later pattern computations, the next step is to adjust the phasing of Slave to Master in such a way that the minimum along the Master-extension becomes exactly zero; for the above example, this obviously requires a phase shift of +0.042 at the Slave transmitter. The adjustment can be made in a few seconds.

As a control, the lanecount now can be repeated and should result in a maximum value of 318.400 and a minimum of 0.000.

7.3. Lanecounts can be made with the receiver in any type of vehicle: a car, a ship or boat, an aircraft or even a combination of these.

For hydrographic and land-survey purposes the patterns are required at sea level. In a car or aboard ship, maxima and minima are indeed observed at this level, but in an aircraft one has to fly at a certain altitude. Fig. 8 is a vertical cross-section along a base extension through a pattern; it will be seen that crossing at 10 km from the station at a flight altitude of 150 metres would require a correction of +0.001 lane to correct to sea-level reading.

Accuracy in determining maxima and minima is increased by taking the mean of a number of crossings; the procedure is illustrated in fig. 9.

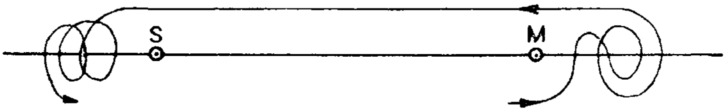


Fig. 9.

7.4. The Green lanecount was carried out by an aircraft, flying at 200 metres (600 ft) altitude and crossing the base extensions at approximately 40 km from the stations; it follows from fig. 8 that the pattern (altitude) corrections are negligible. Eight consecutive crossings were made at each extension. Fig. 10, giving crossings V to VII, illustrates the accuracy of determination of the maximum, being the lower point of the smooth curve drawn through the observations.

> In some publications it is recommended to *compute* the best fitting curve, which theoretically should be a parabola. This however presupposes perpendicular crossing at a constant speed of the vehicle. If the latter is not feasible, the drawing of a smooth curve is to be preferred, because under those circumstances the curve will not be symmetrical.

It will be seen from fig. 10 that the Green maximum has been determined with a standard error of ±0.002 lane. The minimum was determined with equal accuracy, hence the standard error in the number n_G of Green lanes was ±0.003 lane, equivalent to about 1.8 metre (6 feet) or about 1 part in 100 000 of the Green baseline.

7.5. A lanecount by flying around the Red baseline would have been far the easiest method; unfortunately no aircraft could be made available for that purpose. Counting by ship is not possible because the river up to Erambo is much too narrow and shallow. It was therefore decided to count the Red lanes in three steps.

The simplest way to determine the minimum was to cross the Master-extension by ship (deep water in open sea, see fig. 2), the distance to the Master being about 15 km. Four of the eight crossings are plotted in fig. 11. The ship's receiver was now transferred to a landing craft, having a shallow draft, which could go up the Merauke river to a place some distance north of Erambo. As the direction of the Red baseline is north-east and the river makes no turn in that direction, the landing craft could not make the crossing and the receiver — now working on batteries — had to be transferred again to a float, constructed of two native canoes. In this way it was possible to travel across a large area, flooded by heavy rains, and a number of crossings could be made about 12 km north-east of Erambo. The trip was quite an experience because of the many crocodiles and snakes, and took a whole day; the observations were repeated the next day.

The observed maximum was 206.250 lanes with a standard error of ±0.011 lane. As the standard error at the Master extension was ±0.001 lane only, the total number of Red lanes$=n_R$ has been determined with a standard error of ±0.011 lane, equivalent to about 4.5 metres (15 feet) or about 1 part in 20 000 of the Red baseline of 86 km.

The reason for the lower accuracy compared with the aircraft counting of n_G is not that the receiver had to be transferred twice, but most probably the largely random effect of the tree-errors (see section 16) which could not be completely avoided at the Erambo crossing.

7.6. *Summary of lanecounts*

1 Master extensions Red and Green both 0.000±0.001 standard error.

2 Green baseline n_G =318.400 lanes±0.003 standard error.
(1 part in 100 000)

3 Red baseline n_R =206.250 lanes±0.011 standard error.
(1 part in 20 000)

Note: When an aircraft is available, lanecounting in both patterns need not take more than one day when properly planned. Proper installation and testing of the Decca receiver and aerial would take about one day.

8. — PROPAGATION SPEED (PHASE VELOCITY) AT DECCA FREQUENCIES

8.1. Propagation speed is a term widely used in mechanics. It is unlikely to be misunderstood when applied to the propagation of radio waves and will therefore be used throughout this paper. Strictly speaking it is more correct to talk about *phase velocity*, because it is the phase of the radio-wave, or phase-difference, that is the yardstick in a phase comparison system such as Decca and all the formulae are based on the spatial movement of wavefronts.

8.2. It has already been explained why the computed and radiated patterns should agree and to this end — among others — the propagation speed should be known. The theory of Norton-Bremmer fully explains radio wave propagation, but in fairly complex terms. A « Decca Memo » (2) describes the application of this theory to the radio frequencies employed by the Decca system, and contains many graphs which facilitate its practical use.

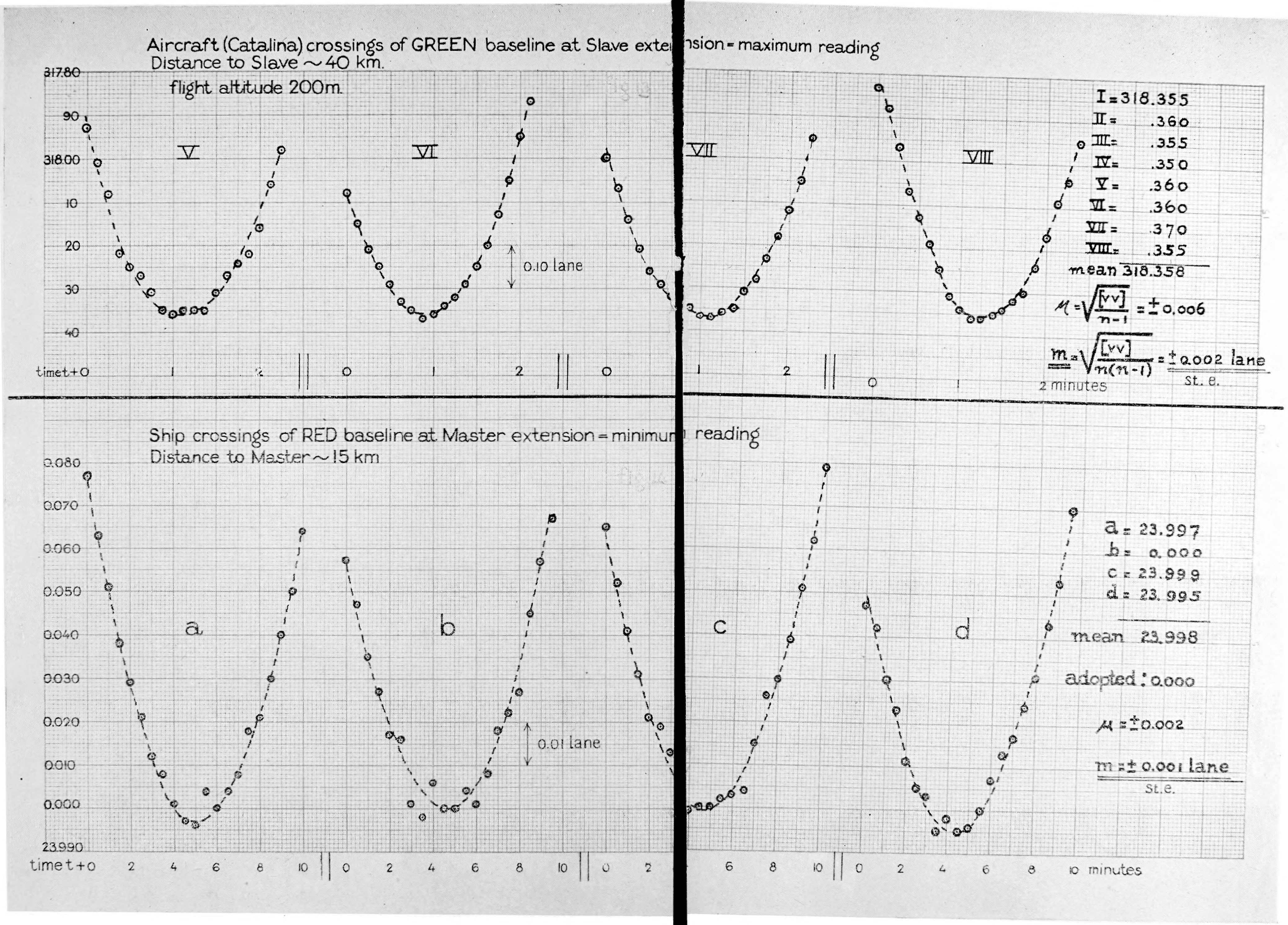

Aircraft (Catalina) crossings of GREEN baseline at Slave exte nsion = maximum reading
Distance to Slave ~ 40 km.
flight altitude 200m.
317.80
90
318.00
10
20
30
40
V
VI
VII
VIII
0.10 lane
time t+0
1
2
0
1
2
0
1
2
0
1
2 minutes
I = 318.355
II = .360
III = .355
IV = .350
V = .360
VI = .360
VII = .370
VIII = .355
mean 318.358
$\mu = \sqrt{\frac{[vv]}{n-1}} = \pm 0.006$
$m = \sqrt{\frac{[vv]}{n(n-1)}} = \pm 0.002$ lane
St. e.
Ship crossings of RED baseline at Master extension = minimu reading
Distance to Master ~ 15 km
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
23.990
a
b
c
d
0.01 lane
time t+0
2
4
6
8
10
0
2
4
6
8
10
0
2
6
8
10
0
2
4
6
8
10 minutes
a = 23.997
b = 0.000
c = 23.999
d = 23.995
mean 23.998
adopted : 0.000
$\mu = \pm 0.002$
m = ± 0.001 lane
St. e.

Fig. 10 a 11.

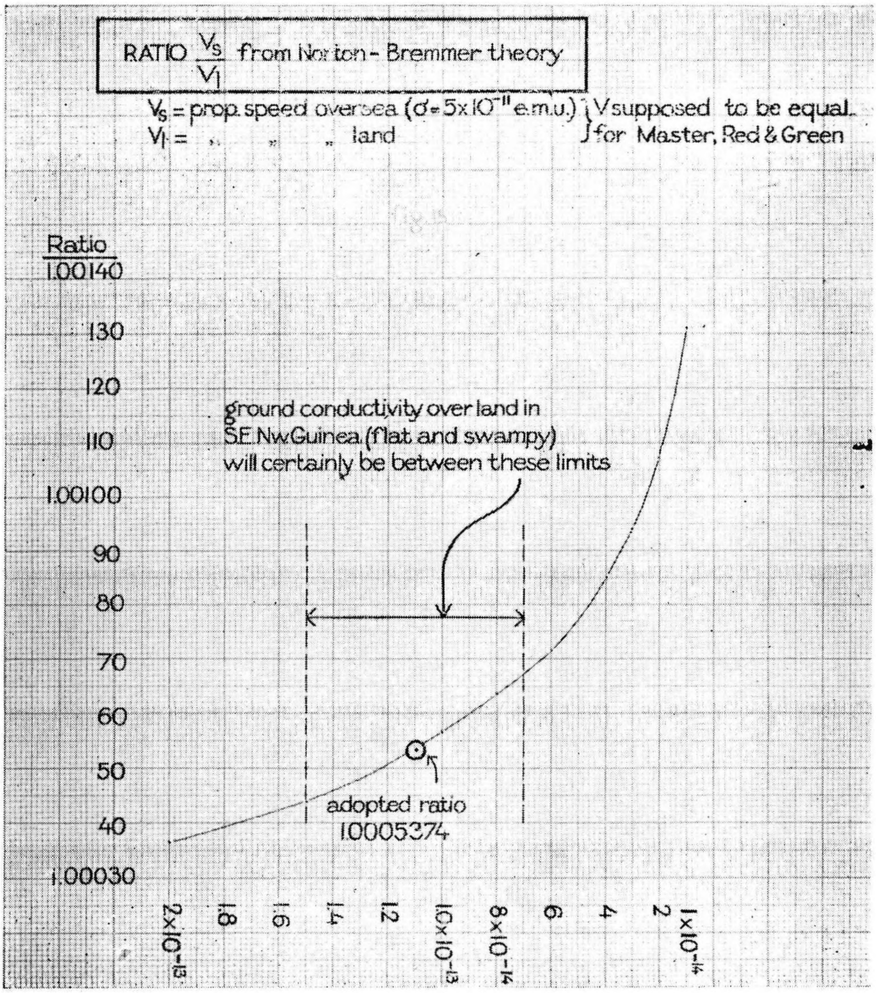

RATIO Vs/Vl from Norton - Bremmer theory
Vs = prop. speed oversea (σ = 5x10⁻¹¹ e.m.u.)
Vl = „ „ „ land
V supposed to be equal for Master, Red & Green
Ratio
1.00140
130
120
110
1.00100
90
80
70
60
50
40
1.00030
ground conductivity over land in S.E. Nw.Guinea (flat and swampy) will certainly be between these limits
adopted ratio 1.0005374
2x10⁻¹³
1.8
1.6
1.4
1.2
1.0x10⁻¹³
8x10⁻¹⁴
6
4
2
1x10⁻¹⁴

Fig. 12.

A great number of factors may affect the propagation speed to a considerable extent. In actual practice — especially in undeveloped countries — some of these factors are unknown and very difficult to determine from measurements and hence the theory cannot always be fully applied. Under these circumstances the most important factors only can be taken into account and a much simplified propagation theory has to be used. As a result, the propagation speed can be predicted or computed to a limited accuracy only, that is to say limited in comparison to the accuracy that can be obtained under circumstances as described in (3a) and (3c). It will be shown, however, that a very limited amount of information can often suffice for quite acceptable accuracy in practice.

The (radiated) Decca frequencies for the New Guinea chain are as follows:—

Master	89 306.0 cycles/second
Red Slave	119 074.6 cycles/second
Green Slave	133 959.0 cycles/second

The theory shows that the propagation speed V is a function of the radio frequency. For the range of frequencies employed by Decca this difference however is very small at the distances of a few hundreds of kilometres at which the system is used for survey work. As far as is known, it has never been possible to show these differences experimentally with sufficient accuracy: the author undertook an effort in 1949, but the root mean square errors proved to exceed the computed differences by a considerable amount.

The first simplification therefore is to assume *V to be independent of frequency* (up to 700 km) for ground of reasonably good conductivity. The actual speed will as a maximum not differ more than 1 part in 30 000 from an adopted value of V and 1 part in 10 000 for low-conductivity ground.

The most important factor affecting the absolute value of V is the electromagnetic conductivity σ of the terrain over which the waves are travelling. Poor conductivity considerably retards the effective speed. For sea water $\sigma = 5 \times 10^{-11}$ e.m.u., while for dry sand $\sigma = 1 \times 10^{-14}$ is a representative value; the difference in V over the two types of terrain at Decca frequencies is as much as 0.14 % or about 1 part in 700 of V. Between sea water and land of average conductivity the difference in V is considerably smaller; figures are given below. When survey-accuracy is required, σ must be taken into account.

It would be possible to do so, when σ is known (3) but in undeveloped countries this is seldom the case and measuring this quantity is not a practical proposition. However, after some simplification of the Norton-Bremmer theory I came to the conclusion that the ratio of sea water speed over land speed $= \frac{V_s}{V_l}$ is an accurately determinable function of σ. This ratio is given in graph fig. 12.

This curve is considered to be of great practical value for survey work.

> The right hand side of the curve rises steeply, indicating that the ratio is quickly changing with change in ground conductivity. Evidently, in order to obtain the ratio with equal accuracy, low-conductivity values should be known more accurately than high.

As already mentioned, in undeveloped country σ is not known at all. By comparing the type of ground with terrain in Europe, where measured values of σ

are available (3), one can however make a very reasonable guess. For the flat and swampy terrain in New Guinea, for instance, the ground conductivity will not differ markedly over different portions of the land area and certainly σ will be within the limits of 1.5×10^{-13} and 7×10^{-14}. This seems to be very much on the safe side and most probably the limits are narrower. Adopting for σ a mid-value of 1.1×10^{-13} results in a ratio:

$$\frac{V_s}{V_l} = 1.0005374$$

and it can be seen from the graph that this value certainly will *not* be in error for *more than* 1 *part in* 10 000. It is this error that has to be accepted as the limiting accuracy factor of the system in New Guinea or elsewhere under comparable conditions.

> For hydrographic and many other types of surveying this degree of accuracy is certainly good enough and could not have been approached by any conventional methods (having regard to local conditions). Regardless of the type of radio system, higher accuracies are obtainable only when σ is known to a higher degree of accuracy (3) or for propagation paths entirely over water.

The second simplification of the full theory, therefore, is the use of a *fixed ratio* $\frac{V_s}{V_l}$ over the whole of the land area.

The propagation speed is also theoretically a function of the meteorological conditions. They are however not at all critical and variation in V due to not too excessive changes in meteorological conditions (in this respect the most important are temperature, pressure and humidity) is not expected to exceed 1 part in 100 000 of V. Compared with other sources of errors, this is negligible.

9. — RELATIONSHIP BETWEEN LANE-NUMBERS AND DISTANCES FROM TRANSMITTERS TO RECEIVER

In a system of consecutive numbering of the lanes, starting with zero along the Master-extension of a baseline, this relationship is as follows for Red and Green (see fig. 13).

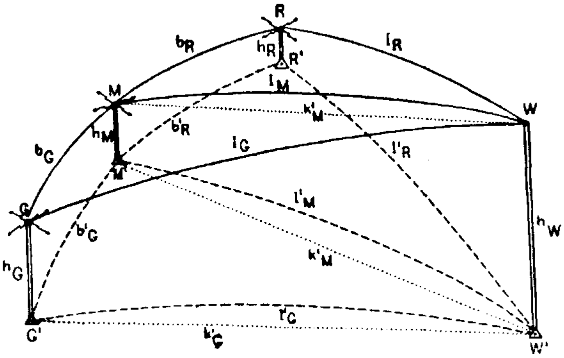


Fig. 13.

$$L_R = \frac{F_R}{V}(b_R + l_M - l_R) \quad \dots\dots (2)$$

$$L_G = \frac{F_G}{V}(b_G + l_M - l_G) \quad \dots\dots (3)$$

where L_R = lane number in Red pattern.

L_G = lane number in Green pattern.

V = propagation speed of radio waves.

b_R = Red baseline.

b_G = Green baseline.

l = distance from a transmitter to the receiver.

In all practical applications at or near sea-level, the heights of the transmitting and receiving antennas can be neglected and the distances b and l can be regarded as equal to the spheroidal distances b′ and l′ (see fig. 13).

10. — DERIVATION OF PROPAGATION SPEEDS AND LENGTH OF THE RED BASELINE

10.1. The relationship between number of lanes = n, length of baseline = b, comparison frequency = F and propagation speed = V is given by formula (1) of section 4:—

$$n = \frac{2bF}{V} \quad \dots\dots (1)$$

For the Green baseline n_G is known (see section 7) and a preliminary value of b_G is given in section 6. The comparison frequencies (i.e. the radiated frequencies after multiplication in the receiver) for the New Guinea chain are:—

F_R = 357 224 cycles/second

F_G = 267 918 cycles/second

The propagation speed can now be computed from (1); as propagation between Master and Green Slave takes place over a mixed land and sea path a mean value V_m is obtained from:

$$V_m = \frac{2b_G F_G}{n_G} \quad \dots\dots (4)$$

$$V_m = \frac{2 \times 178011.9 \times 267\,918}{318.400} = 299\,576\,584 \text{ metres/second.}$$

In order to avoid accumulation of computational errors, this value will not be rounded off.

10.2. The land part of the Green baseline is approximately 67 000 metres and for the rest (178 012—67 000 = 111 012 metres) propagation is over sea. The ratio of sea over land path therefore is $\frac{111012}{67000} = 1.6568955$.

Using the notations V_s over sea and V_l over land, the mean speed V_m can be split up as follows:

$$V_m = \frac{1 \times V_l + 1.6568955\ V_s}{1 + 1.6568955} = \frac{1 \times V_l + 1.6568955 \times \frac{V_s}{V_l} \times V_l}{2.6568955}$$

Now, from section 8 it follows that $\frac{V_s}{V_l} = 1.0005374$

$$V_m = \frac{(1 + 1.6568955 \times 1.0005374)\ V_l}{2.6568955} = 1.0003351\ V_l$$

$1.0003351\ V_l = 299\ 576\ 584$

$V_l = 299\ 476\ 230$ metres/second.

$V_s = 1.0005374 \times V_l$

$V_s = 299\ 637\ 169$ metres/second.

10.3. For the Red pattern, n_R is known from section 7, V_l has just been derived and F_R is also a known quantity. Errors in F are negligible compared with other sources of errors. The length of the baseline b_R can therefore be computed from:

$$b_R = \frac{n_R V_l}{2F_R}$$

$$b_R = \frac{206.250 \times 299\ 476\ 230}{2 \times 357\ 224}$$

$b_R = 86\ 454.1$ metres.

> *To avoid any possible misunderstanding, it should be noted that neither the propagation speeds nor the baselines need be correct in an absolute sense. The importance of this system of computation of speeds and baselines is that it is automatically self-consistent, meaning that — within the limits of accuracy of* 1 *part in* 10 000 — *there may only be an overall error in the scale of the chart.* Absolute scale and azimuth control are discussed in section 15.

Note: The theoretical speed at sea level and over sea water for estimated mean values of meteorological constants in New Guinea is 299 664 km/s, with an estimated uncertainty of the order of 1 part in 20 000. The difference from the computed value of 299 637 is 27 km/s which makes up for 1 part in about 11 000. No further conclusions are possible at this stage because of the uncertainty in the preliminary Green baseline, this having been derived from astro-observations. Later it will be shown that this Green baseline is unlikely to be in error by more than 1 part in about 40 000.

Recapitulation of constants to be used in pattern computation

Red pattern $b_R = 86\,454.1$ metres.

$F_R = 357\,224$ cycles/second.

$V_l = 299\,476\,230$ metres/second.

$n_R = 206.250$ lanes.

Green pattern $b_G = 178\,011.9$ metres.

$F_G = 267\,918$ cycles/second.

$V_m = 299\,576\,584$ metres/second.

$n_G = 318.400$ lanes.

11. — DETERMINATION OF AZIMUTHAL DIFFERENCE BETWEEN THE TWO BASELINES

11.1. It may be seen from fig. 14 that, once a chain has been set up and put into operation, there will be one and only one Green lane passing through the Red Slave and one particular Red lane through the Green station.

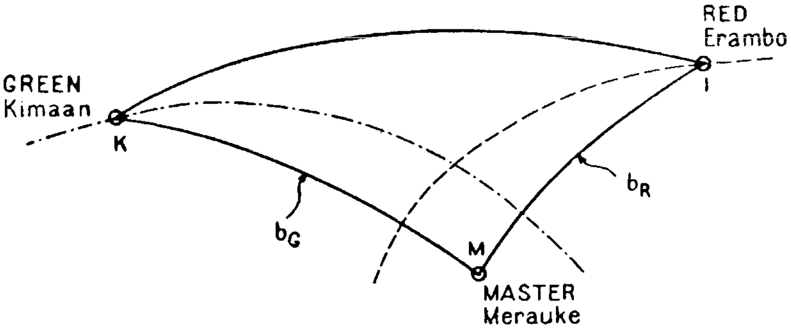


Fig. 14

Provided the length of the two baselines (not necessarily the coordinates of the transmitters) is known, these readings at the Slave sites are evidently each a measure of the angle at M between the baselines.

This angle — on the international spheroid — is computed as follows (see fig. 14):

At the Green station at Kimaan (K): $L_R = \frac{F_R}{V}(b_R + l_M - l_R)$ .... (5)

At the Red station at Erambo (E): $L_G = \frac{F_G}{V}(b_G + l_M - l_G)$ .... (6)

Now, in formula (5) $l_M = b_G$ and $l_R = KE$

and in (6) $l_M = b_R$ and $l_G = KE$

In the recapitulation of section 10 it was mentioned that the Red pattern is computed using V_l, while V_m has been used for the computation of the Green pattern, therefore at K:

$$L_R = \frac{F_R}{V_l}(b_R + b_G) + \frac{F_R}{V_l} \times KE \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$\text{at E:} \quad L_G = \frac{F_G}{V_m}(b_G + b_R) + \frac{F_G}{V_m} \times KE \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

In formulae (7) and (8) L_R and L_G are related to *computed* lane numbers. The available data however are *observed* lane numbers and the two need not be identical, because the actual propagation speeds — which are determining the observed lane numbers — may differ from the speeds used in the pattern computation. For instance in formula (7) along the paths b_R and KE the waves are travelling with the speed V_l, but along b_G they travel with a speed V_m instead of V_l, as has been used in the computation. This difference in speed can be taken into account in the form of so-called « pattern-correction », as will be described in detail in section 14. These pattern-corrections must therefore be applied to the readings K and E before they are used in formulae (7) and (8).

The observations (see fig. 15) are:

at K mean of Red readings	34.398 lanes ± 0.007 standard error.
pattern corr.	+ 0.042
L_R to be used in (7)	34.440 lanes ± 0.007 standard error.
at E mean of Green readings	25.722 lanes ± 0.003 standard error.
pattern corr.	+ 0.078
L_G to be used in (8)	25.800 lanes ± 0.003 standard error.

Now in formulae (7) and (8) KE is the only unknown quantity and a root mean square solution would be possible. As there are only two equations to solve one unknown, the standard error thus computed would be meaningless and therefore the two equations (7) and (8) were solved separately and the arithmetical mean of the two values was adopted.

Using the constants of section 10:

from L_R: KE = 235 593.5 metres.

from L_G: KE = 235 617.3 metres.

mean value of KE = 235 605.4 metres (spheroidal distance).

11.2. The difference between the two determinations is 23.8 metres or 1 part in 10 000 of the distance; although the number of observational equations (2) is far too small, a reasonable guess at the standard error might be $12 \times \sqrt{2} = 15$ metres or about 1 part in 16 000.

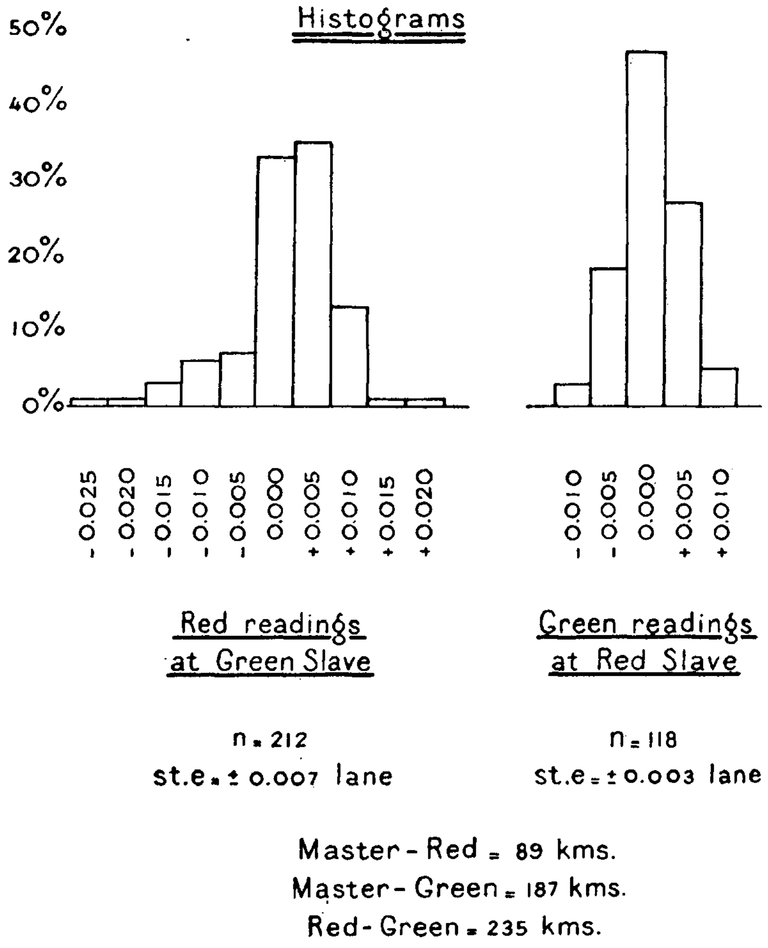


Fig. 15.

This difference can be looked upon also as an indication of the internal accuracy of the spheroidal triangle MEK. In other words one might say that the closing error in this triangle is 24 metres in a total of 500 kilometres; it is admitted that this method of expressing accuracy is debatable, but still it gives an idea of the accuracy obtained.

11.3. The angle KME $= \alpha$KE now can be computed from the spheroidal triangle, in which the three sides are known. In view of the comparatively low accuracy of the length of the sides, this computation can be simplified by assuming KEM to be a spherical triangle; αKE therefore is computed from:

$$\sin^2 \frac{\alpha KE}{2} = \frac{\sin (s - b_R) \sin (s - b_G)}{\sin b_R \sin b_G} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where

$S = \frac{b_R + b_G + KE}{2}$, all sides being in angular units, to be computed for a sphere of radius $\sqrt{\rho N}$ (ρ = mer. curv.; N = curv. in prime vertical; both for the mean latitude in the triangle).

The result of the computation is:

$$
\begin{array}{rcll}
\alpha KE & = & 122^\circ\ 05'\ 00''.20 & \\
\alpha MK & = & 288^\circ\ 35'\ 51''.24 & \text{(from section 6)} \\
\cline{3-3}
\alpha MK & = & 50^\circ\ 40'\ 51''.44 &
\end{array}
$$

12. — COMPUTING THE PATTERNS

12.1. Propagation of the Decca waves is not limited to the horizontal plane and it has already been mentioned that the patterns at a certain altitude are not exactly the same as those at sea level. The difference is zero in the vertical plane through the bisector of a baseline and maximum in a vertical plane through the baseline extensions; even there the difference is small as may be seen from fig. 8.

Since the patterns are not critical as to altitude (except very near the stations), for most practical applications of hydrographic and land surveying, the spheroid can be regarded as a more than sufficiently correct mathematical plane to represent the physical earth's surface at which the Decca phase measurements take place.

12.2. The general computational problem — as it is usually stated — is to get the necessary data to enable plotting of the spheroidal hyperbolic patterns in terms of geographical latitude and longitude (being a coordinate system on the spheroid). The problem is usually stated that way, because it is supposed that a sheet of paper, i.e. the future chart, has already been prepared with a graticule on it in the desired chart projection — Mercator, stereographic, Lambert, or whatever it may be — and/or a grid. It will be seen later that the problem may also be stated in another way.

12.3. There are many different methods of computation, the best known and most widely used being as follows:

(a) a method which I describe as the « British method » (4);

(b) the method of Professor Ballarin (5);

(c) the method of Professor Hugon (6);

(d) the method of Professor Dupuy (7).

Constructional methods have been used in some actual survey projects (8); some of their limitations will be mentioned below.

12.4. In the British method, the lane numbers are computed (separately for each pattern) to any desired number of decimal places by formulae (2) and (3) (other notations are used in British publications) for a great number of intersections of parallels and meridians; inverse interpolation is used to find the exact latitude (or longitude) at which *full* lane numbers intersect successive meridians or parallels. The method requires the chord distances between the chosen intersections of parallels and meridians and the Decca stations to be computed first from reduced (i.e. parametric) latitudes ψ (tg. $\psi = \frac{b}{a}$ tg. ϕ) and geographic longitudes; to these chord distances a correction is applied to reduce them to the spheroidal distances to be used in formulae (2) and (3). The formulae for chord computation are *exact* irrespective of distance and the simplified correction to spheroidal distances is sufficiently correct (1 part in 3×10^6 for distances not exceeding 500 km). Eight decimal places in goniometric functions are required for an accuracy that will always exceed that of the Decca measurements themselves.

The drawback of the method is that inverse interpolation is quite cumbersome, being a process of successive approximations in which — even at fairly long distances where the hyperbolae become straighter — up to 4th or 5th differences have to be used when an accuracy sufficient of 1/25 000 scale plotting is required. 0.01 Decca lane may be as narrow as 4 metres; computational and plotting accuracy should be better than that.

The density of the net of intersections of parallels and meridians and therefore the number of points for which the computations have to be made, increases very rapidly near the transmitters, where the hyperbolae are strongly curved.

The method lends itself to electronic computation, although not in a simple way.

12.5. From a mathematical and geodetic point of view, Professor Ballarin's method is much more elegant, because the intersections of *full* lane numbers of *two* patterns are directly obtained in terms of latitude and longitude and consequently can be plotted in the graticule in any desired chart projection; no inverse interpolation is needed.

Here also eight decimal places of goniometric functions have to be used.

Unfortunately the computations have to be made in several steps, that is to say that the required answer cannot be obtained from one or a few closed formulae. Consequently, the computations are time-consuming and the method does not lend itself easily to electronic computation.

12.6. The methods mentioned under (c) and (d) have been used in France. In Hügon's method a number of points along a certain *full* hyperbola is computed in terms of spherical rectangular coordinates; the two patterns have to be computed separately.

The formulae developed by Dupuy were not intended for the high accuracy that is required for survey work.

12.7. For computing the patterns of the New Guinea chain, it was decided, a year before the chain was set up, to use Ballarin's method. However, during the training of the ship's officers in this method, it became clear that progress in computation would be too slow to keep pace with the expected progress of the survey work and of course a strict requirement is that pattern computation should always be well ahead of the actual surveying.

I therefore investigated whether the computation of flat hyperbolae (very simple formulae and therefore speedy computation) would be acceptable. This proved to be possible in the manner now to be described, and it will be shown that the errors in this method are completely negligible.

Method of computation used in New Guinea (flat hyperbolae)

12.8. Flat hyperbolae are easy to compute with simple formulae but evidently they are not the correct representation of the patterns of spheroidal hyperbolae with respect to which the Decca receiver is measuring.

The idea behind the method is to plot both patterns (in this case Red and Green) of flat hyperbolae in a rectangular grid on a sheet(s) of paper (actually the dimensionally stable material Astralon has been used) and to compute the system of parallels and meridians in such a way that it compensates for the difference between the flat and the spheroidal hyperbolae.

This method leaves no choice as to chart projection, but this limitation was acceptable. Generally speaking, however, the surveyor will prefer to be free in the choice of the chart projection and accordingly another method using flat hyperbolae has been developed in which this choice is left open. Described in a paper to be presented to the XIth IUGG Assembly, entitled « *Standard Sheets of hyperbolic patterns for survey use* », this method is considered to be important not only because of the fact that no computation or construction is necessary, but also because it will do away with the time-consuming and cumbersome drawing of hyperbolae through computed or constructed points.

12.9. The method used in New Guinea is illustrated in fig. 16. For the computation of the flat hyperbolae the baselines ME (Red) and MK (Green) are assumed equal to their spheroidal lengths and their angle of intersection at M is equal to the local difference in spheroidal azimuths $\alpha ME - \alpha MK$.

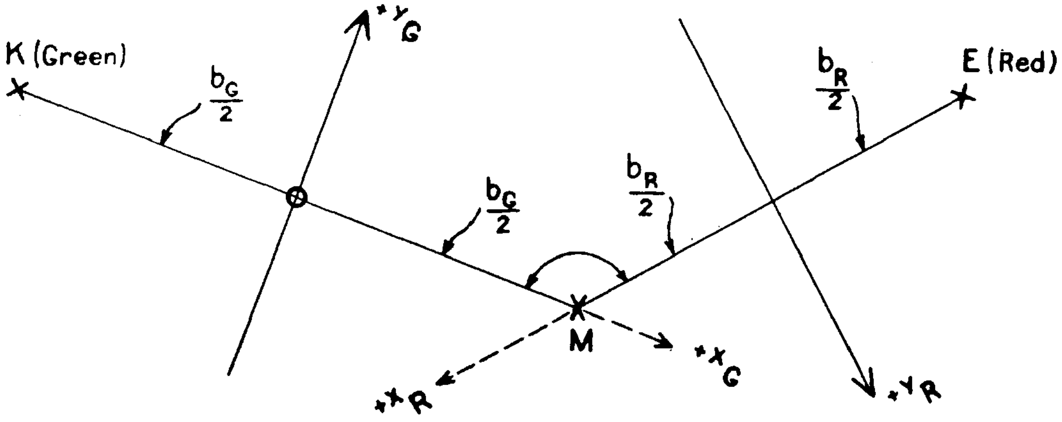


Fig. 16.

This means that the baselines and azimuths are used as they would be in the chart projection of *Postel* with a plane, tangent at M. It should be noted however that nowhere in the computations is use made of the mathematical properties of Postel's projection.

Two separate systems of Cartesian coordinates x_R, y_R and x_G, y_G are adopted. The flat hyperbolae are separately computed for Red and for Green.

The following formulae can easily be derived from the basic equation of a flat hyperbola (fig. 17):

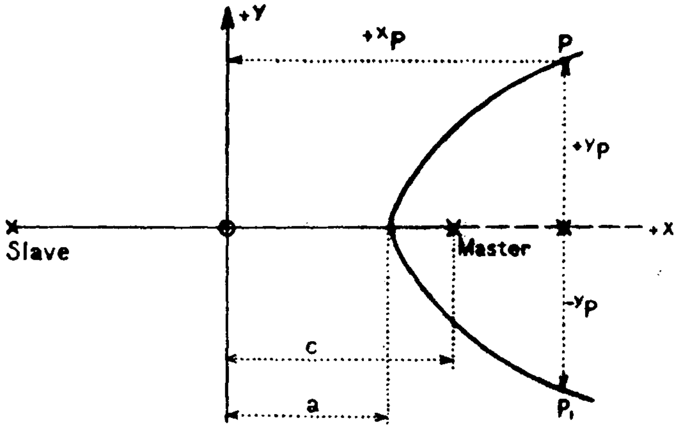


Fig. 17.

$$y_P^2 = (x_P^2 - a^2) . K \qquad \dots\dots\dots\dots\dots\dots \quad (10)$$

$$\text{where } K = \frac{c^2 - a^2}{a^2} \qquad \dots\dots\dots\dots\dots\dots \quad (11)$$

$$a = \frac{b}{2} - \frac{L\Lambda}{2}$$

$$c = \frac{b}{2}$$

b = (spheroidal) length of baseline.
L = lane number.
Λ = wave length of comparison frequency.

K is a constant for a certain hyperbola.

b and Λ are constants for all hyperbolae in a pattern.

12.10. In formula (10) an adopted (rounded off) value of x is now used to compute the corresponding value of +y for the positive and at the same time —y for the negative branch of the hyperbola. This computation has to be repeated for a number of points P along the hyperbola; between 20 and 50 suitably separated values of x, dependent on the curvature of the hyperbola to be computed, will suffice for drawing of the hyperbola as a smooth curve with the aid of splines.

In the region near the transmitters the hyperbolae were computed for each successive full lane number. Near the bisector of the baseline — where the curvature is small — every 5th or 10th lane was computed; the interjacent hyperbolae were later obtained by graphical interpolation.

12.11. These computations have to be carried out separately for the two patterns Red and Green.

Thereafter it would have been possible to plot the computed coordinates in the two Cartesian systems x_R, y_R and x_G, y_G. The plotting would however be confusing because of the two grids that would be necessary. It was therefore considered to be more convenient to transform these coordinates into one single Cartesian system X, Y; such a transformation is very simple on a suitable electric computing machine. A Friden-type 10 × 10 × 20 was used.

12.12. In New Guinea this system X, Y was chosen in such a way that the direction of the Y axis coincided with the meridian through the Master and with its origin located somewhere beyond the left lower corner of the area covered by the Decca chain; this was achieved by *adopting* the following coordinates for the Master:

$$X_M = +250\,000 \text{ metres.}$$

$$Y_M = +250\,000 \text{ metres.}$$

With the adopted values of baselengths and azimuths in M, the coordinates of the two Slaves are:

$$X_R = +316\,883.5 \qquad X_G = +\;81\,283.5$$

$$Y_R = +304\,780.6 \qquad Y_G = +306\,771.4$$

and the transformation formulae from the x, y to the X, Y system are:

$$X_R = -0.773630x_R + 0.633638y_R + 283442$$

$$Y_R = -0.633638x_R - 0.773630y_R + 277390$$

$$X_G = +0.947782x_G + 0.318919y_G + 165642$$

$$Y_G = -0.318919x_G + 0.947782y_G + 278386$$

Coordinates X and Y thus computed for both patterns were plotted on gridded working sheets (Astralon) at the desired scale, which varied between 1/25 000 and 1/100 000. Finally the hyperbolae were drawn as smooth curves with splines.

The accuracy of computed X and Y was of the order of 1 metre and it is estimated that the hyperbolae could be drawn with an accuracy of 0.2 millimetre (better than 0.01 of an inch) at the scale of plotting.

Plotting and drawing took nearly as much time as computation; the whole job could however easily be kept ahead of the progress of the survey work, which was carried out by a single ship.

Construction of patterns

12.13. A Swedish method of construction is described in (8); for some projects this method has been used also by the Decca Co. and by the Royal Shell.

Use is made of a graduated beam compass for drawing concentric circles around the chart positions of the transmitters, plotted in a suitable chart projection. Hyperbolae are drawn through the intersections of these circles.

The arm of the Swedish compass is 7 metres long, representing a spheroidal distance of 350 kilometres at a chart scale of 1/50 000.

The drawback of the method is that stability to within say 0.1 of a millimetre (1/250 of an inch) — corresponding to 5 terrestrial metres or 0.01 lane of the Decca pattern — is very difficult and perhaps impossible to achieve *. The requirement just stated is not excessive, because near the baseline extensions the circles intersect at very small angles and any error in radius of only one of the circles enlarges this, by a factor equal to the *cosecant* of the angle of intersection.

---

* The inherent accuracy of a modern Decca survey chain is about 0.01 under normal (daytime) operational conditions.

Furthermore, the method needs very accurate centring at the position of the transmitters; also the amount of room needed for the construction is excessive, which certainly need not be an objection for office work but would be prohibitive in conditions comparable to those in New Guinea.

Reducing the scale of construction would reduce the dimensions, but would further increase the accuracy requirements provided that an accuracy of 0.01 lane were aimed at. The author claims that earth curvature can be taken into account when setting the radius of the circles. It will be difficult to do this in a sufficiently simple way with the above-mentioned accuracy, because accurate azimuth-and/or-scale-corrections tend to get complicated at distances exceeding say 100 kilometres from the central point or the central meridian of any chart projection.

The possibility of taking into account the effect of various propagation speeds over land and over sea, by applying appropriate corrections to the radii of the circles, is a second claim put forward in (8). In principle this is valid, but to apply the correction accurately may prove rather complicated where the direction of the radio-wave (i.e. the arm of the compass) makes a small angle with the coast line when crossing from land of poor conductivity to sea.

12.14. The construction method is undoubtedly much faster than any of the methods using computation and — depending on the accuracy required — will be useful for certain applications. To retain the inherent accuracy of a modern Decca survey chain seems to be possible only by computed patterns. Once having decided on computation, the accuracy is only a matter of decimal places and this is of no practical importance when table-model electric computing machines of sufficient capacity are used. Admittedly time may not always be available for computation, especially when several survey parties want to start as soon as the chain is in operation.

Neither construction nor computation can start until the coordinates of the transmitters are known and lane counts have been made.

The answer to the problem of making accurate patterns available at very short notice appears to be the method of the « Standard Sheets », mentioned earlier in this paragraph. Not only does it require no computations on the spot, but it also does away with the drawback of both the construction and the computation methods, namely much time-consuming drawing of the hyperbolae.

13. — THE SYSTEM OF PARALLELS AND MERIDIANS (GRATICULE)

13.1. The graticule is intended to enable graphical hyperbolic coordinates (i.e. the Decca readings recorded during the survey and plotted in the hyperbolic chart patterns), to be transformed into geographical coordinates. It is therefore necessary to construct the graticule in such a way that it « compensates » for the difference between the flat hyperbolae in the chart patterns and the spheroidal hyperbolae with respect to which the Decca receiver is measuring.

To this end the lane numbers in the *spheroidal* patterns Red and Green were computed for a number of intersections of parallels and meridians using the « British method » mentioned in Section 12. It would now be possible to plot these computed lane numbers in the *flat* chart patterns; smooth curves drawn through these points would represent the parallels and meridians.

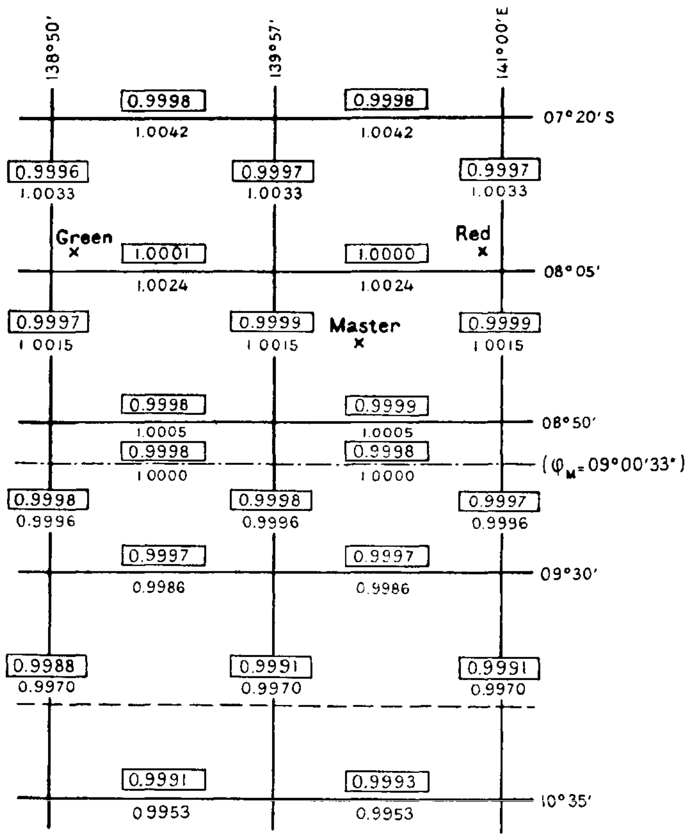


Fig. 18.

In principle there is nothing against this method, apart from the fact that it would not be very accurate especially in places where the Red and Green lanes intersected at a small angle. It was therefore decided to transform the computed spheroidal lane numbers mathematically into rectangular coordinates X, Y, and plot these values in the chart's grid. In this sort of computation any required accuracy can easily be achieved.

13.2. It turned out that the curvature of the parallels and meridians was very slight and that it was sufficient to carry out the computation for 30 intersections only, evenly distributed over the total coverage of 250 × 420 kilometres. Parallels and meridians drawn as straight lines between these points did not deviate more than 0.25 millimetre (0.01 inch) from the theoretically correct curvatures.

13.3. In Fig. 18 the framed figures are the scale factors in this type of chart; they were computed from the differences between computed spheroidal distances and ΔX and ΔY values in the chart. The unframed figures directly underneath are the scale factors as they would have been in the Mercator projection for the mid-latitude of 9° 00′ 33″ S at which the arithmetical mean of the scale factors would be 1.0.

The framed scale factors prove to be very near to 1.0 and indeed they are *more constant than in any known chart projection that could be achieved over such a* *large area.* It should be noted that this favourable property is *independent of geographical latitude* and therefore valid all over the globe.

> Evidently the difference between flat and spheroidal hyperbolae very nearly makes good for the « natural » curvature of the parallels and the convergence of the meridians.

13.4. A question of practical importance for hydrographic survey work is that by international agreement, nautical charts are *published* in the Mercator projection. The chart information from the working sheets must be transferred to Mercator and for practical reasons this should preferably not necessitate complete redrawing.

Fortunately the scale of the published chart is always much smaller than that of the working sheets and consequently small errors in this transfer can be accepted. The usual procedure is a photographic or optical reduction method. Such methods can be used only when the difference in the graticules, resulting from the different chart projections, is within the limits that can be accepted from a practical point of view.

The matter has been investigated for the left lower hand square of fig. 19, obviously the most unfavourable part, because it is there that maximum deviation between the spheroid and the plane of computation of the flat hyperbolae (tangent at M) occurs. That square of 120 × 120 kilometres is represented again in fig. 19, the distortion being of course much exaggerated.

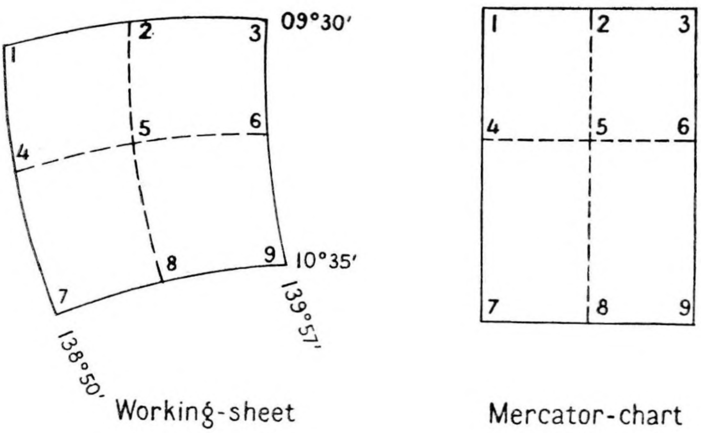


Fig. 19.

The nine intersections of parallels and meridians were computed in X, Y and also in rectangular coordinates in the Mercator projection. A least-square conformal transformation — which mathematically represents the best fitting optical projection of one graticule upon the other — shows a standard error of 78 (terrestrial) metres. As the Mercator nautical chart will be published at a scale of 1/500 000, this would amount to 0.15 mm (0.006 inch) at the scale of publication, being far less than the errors to be expected from irregular shrinking of the chart paper.

It can therefore be concluded that even a most unsuitably located area as large as 120 × 120 km can be optically transferred to the Mercator chart without any measurable error *.

In some mapping or charting projects the desired projection for the chart to be published may be U.T.M. In this case the standard error in the fit of the two graticules would — for the same area — amount to 9 (terrestrial) metres only.

13.5. Although the discrepancies between graticules in different chart projections have been shown to be acceptable from a practical point of view in the production of published charts, attention is drawn once again to the fact that this sort of problem does not present itself when « Standard Sheets » are used.

14. — PATTERN CORRECTIONS DUE TO DIFFERENT PROPAGATION SPEEDS OVER LAND AND OVER SEA

14.1. As has been explained in section 10, the following propagation speeds have been used for pattern computation:

Red pattern $V_l = 299\,476\,230$ m/s

Green pattern $V_m = 299\,576\,584$ m/s

These speeds have been used throughout the computed chart patterns, irrespective of the fact that the waves from transmitters to receiver are actually travelling along paths l_M, l_R and l_G, which may lie partly over land and partly over sea, and thus are travelling at different speeds. As a result these mathematically-computed patterns will not exactly agree with the physically existing lines of equal phase-difference with respect to which the Decca receiver is measuring. As an example, in the Red pattern the Speed V_s** should have been used for those parts of the trajectories l_M and l_R where propagation takes place over sea, while V_l would have been correctly used for the land-paths (fig. 20).

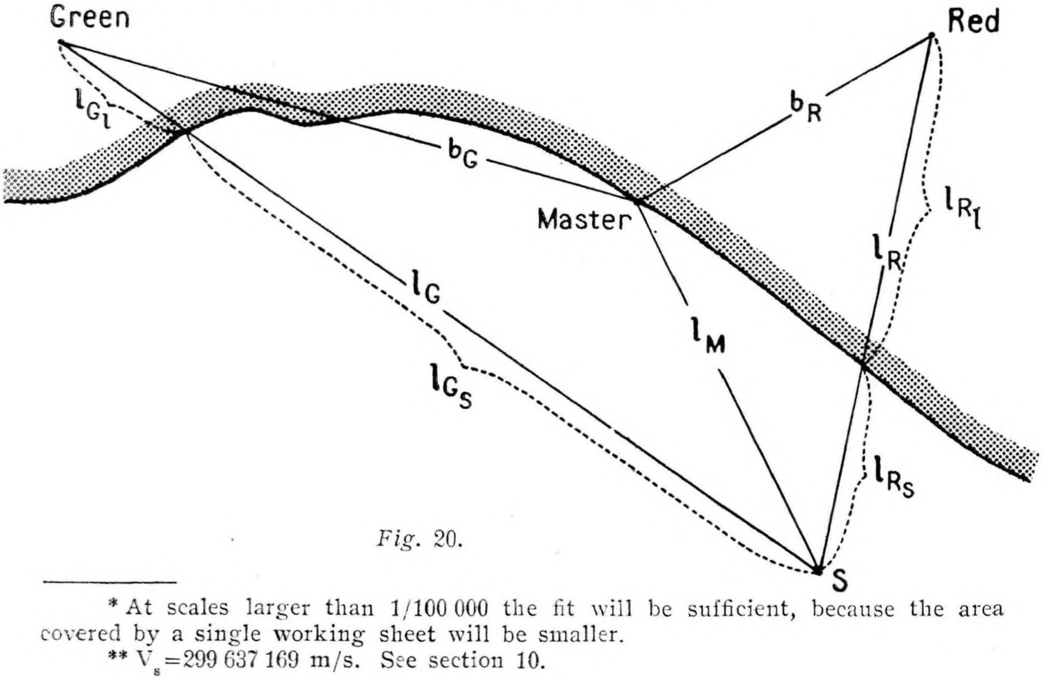


Fig. 20.

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* At scales larger than 1/100 000 the fit will be sufficient, because the area covered by a single working sheet will be smaller.

** $V_s = 299\,637\,169$ m/s. See section 10.

14.2. Theoretically it is possible to split up the distances l_M, l_R and l_G in formulae (2) and (3) of section 9 into as many parts as there are different propagation speeds applicable. Even restricting this to only two different speeds, one for land and one for sea, would greatly complicate the computation and drawing of the patterns since the curvature of the « hyperbolae » would no longer be smooth.

14.3. These anomalies are by no means peculiar to the Decca system; in fact other medium-range radio position-fixing systems can be affected to a higher degree.

14.4. The way out of the computational complications is to compute the chart patterns with the above-mentioned speeds V_l for Red and V_m for Green and to apply *corrections to the decometer readings,* computed in such a way that they compensate for the difference between the computed mathematical chart hyperbolae (either spheroidal or, in the case of New Guinea, flat) and the actual lines of equal phase difference. These decometer corrections will be given in the form of a *correction chartlet.*

14.5. The computation of these corrections proceeds as follows:—

Formulae (2) and (3) of section 9 are valid in the computed chart patterns:

$$L_R = \frac{F_R}{V_l}(b_R + l_M - l_R) \quad \text{.................} \quad (2a)$$

$$L_G = \frac{F_G}{V_m}(b_G + l_M - l_G) \quad \text{.................} \quad (3a)$$

The situation in New Guinea is given in fig. 20.

Along the two baselines b_R and b_G the propagation speeds are V_l and V_m their value having been determined as described in sections 8 and 10.

For an arbitrary point S, l_R is partly over land and partly over sea. The land path is equal to l_{R_l}, and the waves are travelling at a speed V_l; the speed along the sea path $l_{R_s} = l_R - l_{R_l}$ is V_s.

From the Master to S (in this example) the waves are travelling entirely over sea; in a more general case they may however go partly over land and partly over sea. The distance l_M is therefore also split up into a land path l_{M_l}, with speed V_l and a sea path l_{M_s} along which the wave is travelling at the speed V_s.

> It should be remembered that the conclusion of section 8 was that distinguishing between only two different speeds V_l and V_s will suffice for an accuracy of 1 part in 10 000 or perhaps better; that conclusion is valid for the New Guinea chain, but will hold also in other situations, provided the changes in ground conductivity are not too large.
>
> Wherever detailed information on ground conductivity is available, the split should be carried through in more detail; see for examples (3a), (3c) and (9).

14.6. The lane numbers agreeing with the actual lines of equal phase difference are denoted by L'_R and L'_G and then equations are derived as follows by splitting up (2a) and (3a)

$$L'R = \frac{F_R}{V_l} \times b_R + \frac{F_R}{V_l} \times {}^{l}m_{l} + \frac{F_R}{V_s} \times {}^{l}m_{s} - \frac{F_R}{V_l} \times {}^{l}R_{l} - \frac{F_R}{V_s} \times {}^{l}R_{s}$$

$$L'R = \frac{F_R}{V_l} \times b_R + \frac{F_R}{V_l} \times {}^{l}M_{l} + \frac{F_R}{V_l} \times \frac{V_l}{V_s} \times {}^{l}M_{s} - \frac{F_R}{V_l} \times {}^{l}R_{l} - \frac{F_R}{V_l} \times \frac{V_l}{V_s} \times {}^{l}R_{s}$$

In this last formula $\frac{V_l}{V_s} \doteq 0.9994626$ (see Section 8).

$$\mathbf{L'R} = \frac{F_R}{V_l} \left\{ b_R + {}^{l}M_{l} - {}^{l}R_{l} + 0.9994626\,({}^{l}M_{s} - {}^{l}R_{s}) \right\}$$

$$L'R = \frac{F_R}{V_l} \left\{ b_R + {}^{l}M_{l} - {}^{l}R_{l} + {}^{l}M_{s} - {}^{l}R_{s} - 0.0005374\,({}^{l}M_{s} - {}^{l}R_{s}) \right\}$$

$$L'R = \frac{F_R}{V_l} \left\{ b_R + {}^{l}M - {}^{l}R \right\} - \frac{F_R}{V_l} \times 0.0005374\,({}^{l}M_{s} - {}^{l}R_{s})$$

or, substituting $L_R = \frac{F_R}{V_l} \left\{ b_R + {}^{l}M - {}^{l}R \right\}$

$$L'R = \mathbf{LR} - \frac{F_R}{V_l} \times 0.0005374\,({}^{l}M_{s} - {}^{l}R_{s})$$

14.7. If it were required to correct the pattern computed from (2a), the correction would be $-\frac{F_R}{V_l} \times 0.0005374\,(l_{M_s} - l_{M_R})$ or $-64.09114 \times 10^{-5}\,(l_{M_s} - l_{R_s})$... *(distances expressed in km)*.

14.8. The computed patterns however have been charted uncorrected and therefore, after applying a
correction to the Red decometer readings of $+64.09114 \times 10^{-5}\,(l_{M_s} - l_{R_s})$ km (12)
the decometer readings can be correctly plotted.

A similar formula can be derived from the Green pattern:
correction to the Green decometer readings

$$+18.68863 \times 10^{-5}\,(l_{M_s} - l_{G_s}) \text{ km} - 29.38317 \times 10^{-5}\,(l_{M_l} - l_{G_l}) \text{ km} \qquad (13)$$

As the multiplication factors in formulae (12) and (13) are small, it is sufficiently accurate to scale off the length of the sea (or land) paths from an existing small-scale chart.

Note: This method of computing corrections is roughly similar to the methods described by H. Larsson in (8) and (9) and by P. Hugon in (10).

14.9. Formulae (12) and (13) have been used to compute the corrections to the decometer readings for a great number of intersections of parallels and meridians all over the coverage of the chain (fig. 2). These values were plotted and smooth correction curves were drawn on two separate correction chartlets for Red and Green,

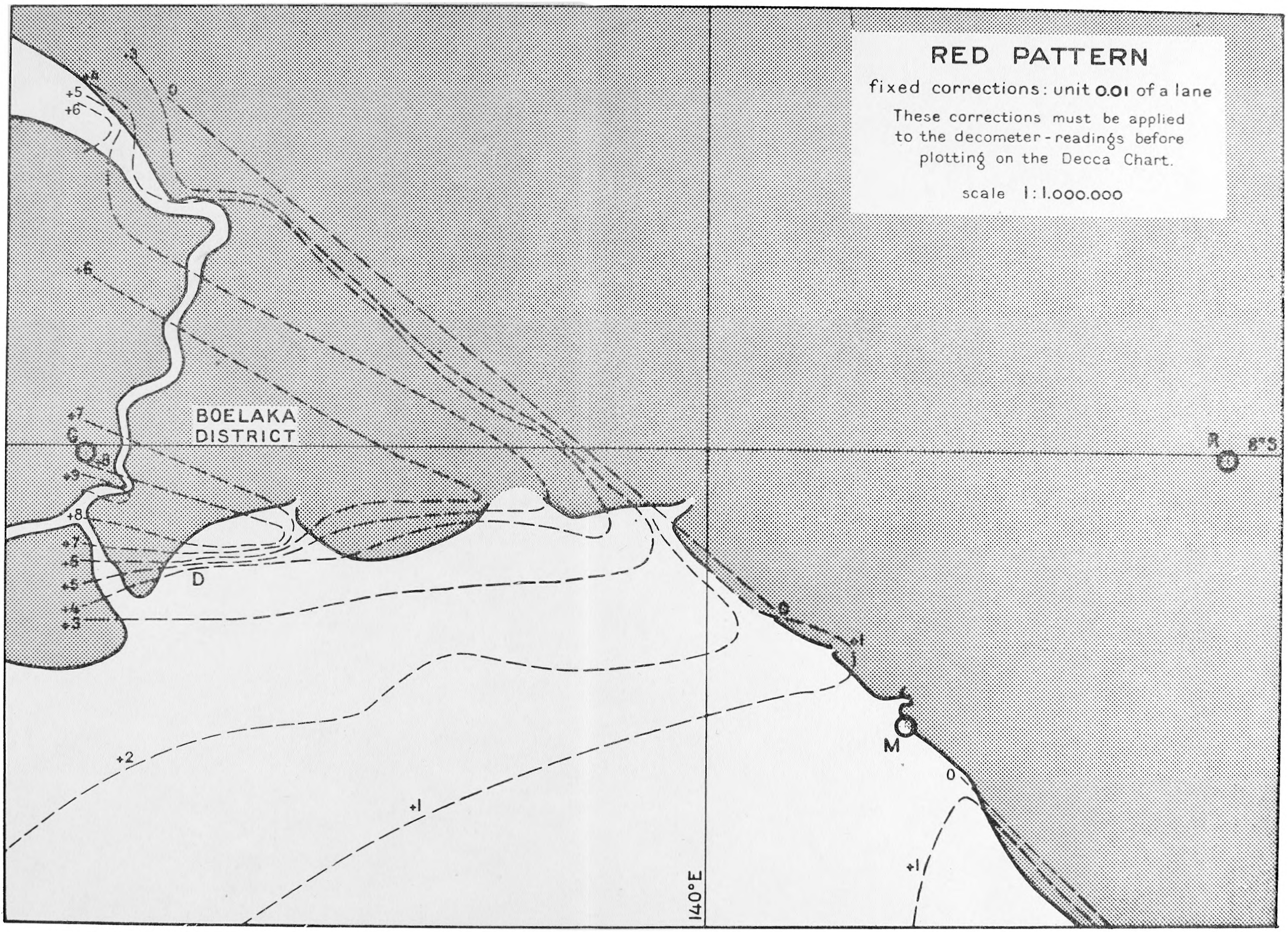
RED PATTERN
fixed corrections: unit 0.01 of a lane
These corrections must be applied to the decometer-readings before plotting on the Decca Chart.
scale 1:1.000.000
BOELAKA DISTRICT
140°E
8°S
R
C
D
M
+3
0
+4
+5
+6
+6
+7
+8
+9
+8
+7
+6
+5
+4
+3
+2
+1
0
+1
0
+1

Fig. 21.

both chartlets at the scale of 1/1 000 000. Computation and plotting took two man-days for Red and three for Green.

Fig. 21 is a reproduction of a section of the correction chartlet for Red. As the Red pattern has been computed with V_l, the corrections are zero at any location where both l_M and l_R are entirely over land, that is for the whole of the land coverage of the Red pattern except the Boelaka district. It is in this part of the land coverage that l_M is partly *over sea;* in the very Southern corner of this district l_R also is partly over sea. The rate of change of the correction, when moving from one place to another, is maximal there, where the sea paths change quickly in length for different azimuthal directions to Master and/or Red, as may clearly be seen from the chartlet.

At sea the curves are widely separated, except near D, where l_{R_s} is quickly changing. It is near D that the maximum rate of change of 0.01 of a Red lane over about 1 kilometre occurs, in the direction perpendicular to the coast.

14.10. The correction chartlet clearly demonstrates a phenomenon which is usually described as the *coastal effect,* well known in radio direction finding (D.F.); the usual description is that the waves are « bent » in azimuth when crossing the coast line from land to sea. Experience indicates that this effect is more pronounced when the coastline is crossed at a small angle.

> Experience also shows that « bending » may be considerable when the direction-finding station is located on badly conducting ground, the reason being that most such stations operate at radio frequencies at which the difference between V_l and V_s is considerably larger than at the Decca frequencies. The siting of a D.F. station (or any radio-navigation station operating at similar frequencies) is therefore more critical than for a Decca transmitter.

In analogy to the propagation of light waves, there seems however to be no reason why the azimuthal direction of radio-wave propagation should actually undergo a change when passing from land to sea: evidently it is the change of propagation speed that causes this *apparent* effect of bending. (The lines of equal phase difference are « displaced » in a direction perpendicular to the correction curves. When these corrections are not taken into account in plotting the line of position, this results in an error in the azimuthal direction from observer to transmitter).

15. — DETERMINATION OF ABSOLUTE SCALE AND AZIMUTH

15.1. In preceding sections it is described how the chart patterns have been made self-consistent and how the scale and azimuthal orientation of the combined Red and Green patterns have been made *dependent only on the length and azimuth of one single line,* the Green baseline.

Any (unknown) plumbline deflections at the two astro-stations M and K affect the length and azimuth of this line, or rather the *difference* in plumbline deflection because the absolute value only affects the geographical coordinates of the Master. The observed coordinates of the Master

$$\varphi M = 08^\circ\ 30'\ 22''.37\ \mathrm{S}$$
$$\lambda M = 140^\circ\ 22'\ 33''.05\ \mathrm{E}$$

were accepted, thus including any possible deflections; this was considered to be of no practical importance in New Guinea, because it would affect only the absolute position on the earth of the whole of the survey.

15.2. Obviously, the combined patterns could be brought to the correct scale and azimuthal orientation from terrestrial measurement of the Green baseline, but in country like New Guinea it would not be a practical proposition to measure this whole baseline of 178 kilometres.

The original intention was to measure a 40-kilometre section roughly in the middle of the baseline and along a sandy beach by means of Bergstrand's Geodimeter, to determine the azimuth of this line and to compare the results with the geoidal length and azimuth of that section as computed from the difference in Decca readings at the two terminals. The difference between the terrestrial and Decca values at them gives the scale and azimuth correction.

The Geodimeter is a very fine instrument for accurately measuring such a distance, which would have required three or four steps owing to earth curvature. Unfortunately, however, the local conditions (among them the heavy surf on the beach) would have involved unacceptable risks in bringing the Geodimeter ashore.

As a substitute, a less accurate control by means of a precision traverse had to be accepted. The most suitable stretch for this control was the sandy beach between Merauke and Bian (B in fig. 2), about 61 kilometres to the West. This distance was measured in steps of 100 metres or less, using a Wild 2-metre (horizontal) invar substance bar, which was calibrated before and after measurements and showed no detectable systematic errors.

As the total distance was measured four times, the root mean square error in the mean value could be computed. The measurements included 40 astronomical determinations of azimuth.

It has already been mentioned that the phasing of the Master and Slaves is adjusted in such a way that zero phase difference exists along the Master extensions of both baselines, which also means that the Decca coordinates Red and Green are zero at M. Only at B (the west terminal of the traverse) was it therefore necessary to observe the Decca coordinates. This observation was made over a period of two days, during daylight hours. The result was:

Red	40.955	lanes ± 0.003 standard error.
pattern corr.	+0.019	
Red	40.974	lanes ± 0.003 standard error.
Green	103.808	lanes ± 0.003 standard error.
pattern corr.	+0.028	
Green	103.836	lanes ± 0.003 standard error.

From these corrected readings the Decca spheroidal distance and azimuth from M to B were computed by means of the formulae of Professor Ballarin (5):

$S = 61\,714.40$ metres ± 2 m. st.e. $\alpha MB = 311^\circ\, 40'\, 01''.81 \pm 14''$ st.e.

The spheroidal distance and azimuth MG computed from the precision traverse were:

$S = 61\,715.66$ metres (st.e. 1.52 metre)

$\alpha MB = 311^\circ\, 40'\, 34''.62$ (st.e. 15″)

The control therefore resulted in a difference between terrestrial and adopted values of:

1.26 metre in distance
and
32″.81 in azimuth.

15.3. As these differences are of the same order of magnitude as the standard errors in the determination, they were not considered to be real and it was concluded that the scale and azimuth adopted in the pattern computations needed no correction. This result of course is largely a matter of good luck because of the fact that there happened to be no measurable difference in plumbline deflection between Master and Green Slave.

If the difference had proved to be of any practical importance, it would not have been necessary to recompute the patterns; the error in scale and azimuth could much more easily have been taken into account by a recomputation of the graticule of the chart.

15.4. Taking into account the uncertainties (standard errors) in the Decca observations as well as those in the traverse, it may be concluded that the adopted propagation speed $V_m = 299\ 576\ 584$ m/s *will be correct to within about* 1 *part in* 40 000.

The definitely adopted coordinates for the Green Slave therefore remains unchanged as observed (see section 6):

$$\phi_G = 07° \ 59' \ 23''.82 \text{ S}$$
$$\lambda_G = 138° \ 50' \ 44''.02 \text{ E}$$

and the geographical coordinates of the Red Slave in the definitely adopted framework are:

$$\phi_R = 08° \ 00' \ 37''.58 \text{ S}$$
$$\lambda_R = 140° \ 58' \ 57''.08 \text{ E.}$$

16. — OVERALL ACCURACY OF A DECCA FIX AT SEA AND ON LAND

16.1. A uniform yardstick throughout the whole coverage of the chain is to express accuracy in fractions of a lane. On the New Guinea chain, standard error *in one single isolated Decca reading,* as computed from monitor observations, varied between ±0.005 and ±0.009 of a lane. In practical surveying — where not every possible measure is taken to ensure ultimate accuracy — this error can safely be estimated to be ±0.01 of a lane (standard error).

The accuracy of a *fix,* expressed in terrestrial metres, is governed by the geometrical properties of the patterns, including their local angle of cut.

Because of the geometrical expansion or widening of the lanes, 0.01 of a Red lane *in the New Guinea chain* may vary between 4.2 and 25 terrestrial metres and between 5.6 and 30 metres for a Green position line (hyperbola). In 80 % of the coverage, however, the effect of the lane expansion does not exceed 18 metres and in the remaining 20 % of the coverage the maxima of 25 (Red) and 30 metres (Green) seldom occur simultaneously. An exception has to be made very near the Master extension of Red; further details are given in section 17.

Apart from the above-mentioned accuracy of each of the position lines, the *fix-accuracy* is dependent also on the angle of cut of the hyperbolae. In the New

Guinea chain this angle varies between 90° and 25°, the smaller angles being far out at sea where high fix-accuracy is not required. The *standard error in the fix* (for one single observation of Red and Green) for 80 % of the coverage can be computed to vary between 8 and 30 metres. In the remaining 20 % of the coverage. the standard error varies between 25 and 65 metres.

16.2. To those who think in terms of the accuracy of a first or second order triangulation, these accuracies will appear low. Here it should be noted in the first place that it is perfectly possible to set up a Decca chain having far greater accuracy; for instance, in the very near future a Decca survey chain will be installed (not in New Guinea), covering 7 000 sq. km and permitting accuracies between 2 and 6 metres. The requirement for the New Guinea chain was a coverage as large as possible and an accuracy not necessarily exceeding the drawing accuracy (0.2 of a mm or about 0.01 of an inch) at the *scale of publication* of the charts, which is 1/100 000 and for the open-sea areas considerably smaller still.

Secondly, it must be remembered that, when necessary, the accuracy can be improved by a factor $\sqrt{n}$ (where n is the number of observations) by taking the mean of a number of observations.

Finally, a very important factor which makes lower accuracy acceptable is that in systems like Decca — in contrast with many terrestrial methods — there is no accumulation of errors.

16.3. The accuracy figures given above take into account *random* errors only. Since no terrestrial triangulation existed, there was no possible method of control in respect to *systematic* errors, i.e. systematic differences between the computed and radiated patterns. However, as a result of the method followed in the computation of the patterns and of their fixed corrections due to difference in propagation speed over sea and over land, there is definitely no reason to expect any systematic error that will exceed the general limit (with the New Guinea chain) of accuracy of about 1 part in 10 000.

16.4. A Decca reading on land (using a special one-man-pack receiver with batteries and a whip-antenna) may be affected by a kind of local systematic error which is usually called the « tree-error ». An isolated tree or group of trees is apt to pick up some of the energy from the passing waves, radiated by the transmitters, and under certain circumstances may reradiate a small amount of that energy. The receiver, of course, is unable to distinguish between the desired and the (weak) reradiated signal and will respond to the resultant phase.

In the swamps north-east of Erambo (see section 7) and also elsewhere, the effect of reradiation could be studied in considerable detail. No measurable effect could be observed at a distance of more than 20 metres from a tree or group of trees and even at 15 metres the phase change did not exceed 0.02 of a lane; very near or under a tree the phase shift may exceed 0.10 of a lane.

For Decca surveying on land it is therefore always desirable to take the observations in an open area; when surveying a river, for example, the readings should not be taken too close to the wooded banks.

A method of correcting for tree-errors has been described in Decca handbooks and other publications. The results of trials in Great Britain and in the Netherlands are also published in (11). This correction method has not been used in New Guinea, because observations too close to trees could be avoided, and it was therefore not considered necessary to purchase the additional equipment that would have been necessary for its application.

16.5. The synchronization of the transmitters is automatically and continuously monitored by the receiver permanently located at the Master station. While this is an inherently reliable method of observing that the two radiated patterns occupy their correct positions in space, a separate and independent check is desirable. This consists in periodical recrossings (say once every month or two) of a suitably located base-extension; in New Guinea this is the Master extension of the Red baseline just offshore near the ship's base, Merauke. The minimum value along that extension had been set at 0.000 and therefore should remain at that value. If the minimum value should change, this would mean that the whole Red pattern must have shifted by the same amount and an appropriate correction would have to be applied to the phasing at the Slave station.

Similar control on the Green pattern could readily be effected by crossing the Green extension at the local airstrip east of Merauke.

Except on one occasion, where a Red reading of +0.04 lane turned out to be caused by a small defect in the transmitter, all the readings fell within the limits of 0.000 and 0.02 lane.

> The monitor receiving mast is located only a few hundred yards from the Master, that is to say within the induction field of the transmitter. Changes in ground conductivity just near the Master transmitter — for instance in the area covered by the ground-mat — *may* affect the monitor registration, which would then apply a wrong correction to the *whole* pattern.
>
> The lane-crossings, however, are made outside the induction field and therefore indicate real changes in the patterns, these readings being unaffected by this sort of purely local error very close to the Master. When ultimate accuracy in synchronization is required, it might therefore be worth placing the monitor outside the induction field (extending to about 4 or 5 kilometres from a transmitter). As this would require a separate operator for the monitor, necessitating extra personnel and housing, the possibility of these small errors of 0.02 lane was thought to be acceptable for the New Guinea chain.

16.6. About a year after the chain had been put into operation, Decca coordinates were observed for two days in two locations named Badé and Képi, indicated in fig. 2 by black squares.

The standard errors in the *mean value* computed from 180 observations at each of the two stations, amounted to:

Badé	Red	±0.0004 lane	
	Green	±0.0007 lane	
		(Red	±0.006 lane in a single observation)
		(Green	±0.009 lane in a single observation)
Képi	Red	±0.0005 lane	
	Green	±0.0007 lane	
		(Red	±0.006 lane in a single observation)
		(Green	±0.009 lane in a single observation)

After applying the pattern corrections (section 14) these readings were used to compute by the formulae of Ballarin (5) the geographical coordinates of the two locations in the adopted framework of Master and Slaves:

Badé $\varphi = 07^\circ\ 09'\ 51''.67$ S $\pm 0''.10$ (=3m) standard error.
$\lambda = 139^\circ\ 35'\ 23''.67$ E $\pm 0''.11$ (=3m) standard error.

Képi $\varphi = 06^\circ\ 31'\ 08''.92$ S $\pm 0''.16$ (=5m) standard error.
$\lambda = 139^\circ\ 19'\ 35''.91$ E $\pm 0''.16$ (=5m) standard error.

These small standard errors in the geographic coordinates should not, of course, be looked upon as an absolute measure of accuracy. Nevertheless, the conclusion must be that the accuracy of tying-in these two stations to the adopted framework is far better than could have been achieved by any other means available in this flat and swampy terrain.

Badé and Képi are two of the possible future sites for Decca transmitters when the time comes to move the chain after the survey of the area of fig. 2 has been completed.

16.7. In section 3 it has already been mentioned that the signal-to-noise level is the determining factor for good and accurate functioning of the receiver and it has been shown that — under average conditions of atmospheric noise — the maximum range of the New Guinea chain is of the order of 400 km or possibly even more. Under adverse noise-conditions, however, all types of radio communication are severely limited in range and reliability. Compared with many other systems, Decca is in a favourable position because of the very narrow bandwidth of the receiver.

Practical experience in New Guinea — one of the tropical regions with the world's highest noise-levels — was that a heavy thunderstorm as close as 10 miles did not affect the decometer readings by more than plus/minus 0.02 of a lane. The effect of a still closer heavy thunderstorm amounted on a few occasions to 0.10 of a lane and once, when an electrical storm passed within two miles of the ship, not more than a full lane was lost.

On no occasion was it observed that a thunderstorm passing over or near a transmitter, affected the radiated patterns to an amount exceeding 0.002 of a lane.

The noise-level during the afternoon hours is nearly always considerably higher than in the morning; see also fig. 6. Measurements requiring ultimate accuracy (among them those in Badé and Képi) should therefore preferably be taken befoe noon, although the higher noise-level during the afternoon does not generally affect the decometer readings to more than 0.01 of a lane or 0.02 at the most (excepting, of course, the very near thunderstorms already mentioned).

Summarizing the experience of about a year, it may be said that excessive noise-level did not interrupt the survey work for more than 2 % of the normal working hours between 7 a.m. and 5 p.m. and that the slightly reduced pattern stability in the afternoon could be fully accepted.

16.8. So far, no systematic observations have been made in New Guinea during the night. The few observations that were taken at distances exceeding 200 kilometres, seem to indicate that the effect of sky wave was unexpectably small between 5 and 7 a.m. and between 5 and 8 p.m. (sunrise and sunset in New Guinea are at 6 a.m. and 6 p.m. throughout the year). The formation and disappearance of the reflecting layer * in the tropics therefore appears to be governed by other laws than in higher latitudes; the number of observations, however, is far too small to enable any definite conclusions to be made yet.

Although of no practical value for surveying, which is always limited to the daylight hours, it would be of considerable theoretical value to study the phenomenon of sky wave in the tropics in detail from systematic night-time monitor observations.

16.9. Contrary to Decca navigational chain practice, a system of lane-identification is not usually considered necessary in a survey chain and it was not provided for New Guinea, since a surveyor is assumed to be able to estimate position with sufficient accuracy to the nearest lane.

The survey chain, however, is not working continuously and is normally switched off at 5 or 6 p.m. **. The next morning, therefore, the ship needs some means of checking whether it starts the survey again in the correct lane. In sight of land this offers no difficulty; out at sea it was achieved either by anchoring before the chain was switched off late in the afternoon, or by returning to a place where a buoy had been laid at known Decca coordinates.

Although no serious difficulty was encountered in keeping the correct lane numbers, for work out at sea — where anchoring is not always possible — it would have been more convenient had a full or modified system of lane-identification been available.

17. — ACCURACY OF POSITION FIXING NEAR THE MASTER EXTENSION OF THE RED BASELINE

17.1. Near a baseline extension the lanes get very wide and 0.01 of a lane will be equivalent to a large number of metres in the terrain. A geometrical requirement for siting the transmitters therefore is that all baseline extensions should preferably be outside the area of coverage.

In New Guinea this was achieved for two of the four extensions, but was not possible for the Master extensions of both Red and Green because the terrain offered too little choice of usable sites in this respect (see section 2). As may be seen from fig. 2, the Green Master extension is over land, but fortunately this uninhabited area east of Merauke is of very little importance from the point of view of accurate position fixing. However, the area left and right of the Red extension southwest of Merauke covers an important sector of the sea and some means must be available to fix the position of the soundings there with sufficient accuracy.

For this sea area two solutions suggest themselves, namely to set up a third Slave at some geometrically suitable location (which was completely out of the question here), or to leave out from the first coverage (fig. 2) a sector left and right of the Red extension and survey that sector from a second set-up of the chain. For instance, the Erambo transmitter could be moved to a village by the name of Okaba,

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* At Decca frequencies this is mainly the D-layer at a height between 70 and 80 km.

** In the Decca system the permanent monitor receiver provides a check that the radiated patterns are reconstructed in exactly the same way when the chain is switched on again. The subdivision of a lane as indicated on the decometers is always (automatically) correct.

about half-way between Merauke and Kimaan. This second set-up would cover that sector with adequate accuracy and would necessitate a minimum of moving of equipment and housing. Even so, in a country like New Guinea it would be no small undertaking just to cover such a comparatively small area.

17.2. Before considering a later move to Okaba, it was therefore thought to be more practical to investigate the possibilities, requirements and accuracies in greater detail. The final decision was based on the following considerations:—

The unfavourable sector is far out at sea (near Merauke the Red lanes are still comparatively narrow and in addition terrestrial position fixing is possible) and the first requirement in hydrographic surveying is to run parallel lines of soundings, approximately perpendicular to the lines of equal depth as shown in section 1. The Green pattern Merauke-Kimaan offers the possibility of accurate mutual separation of these lines and hence of a systematic investigation of the profile of the invisible sea-bottom. The only difficulty is that the intersecting Red pattern in this sector has lanes that are too wide to give accurate information as to the distances travelled along the Green hyperbolae. Monitor observations and geometrical considerations made it clear from the outset that the Red hyperbolae of 1.00 left and right from the base extension would give sufficiently accurate information. The *maximum* distance along a Green hyperbola in these « cross-overs » (left-hand lower corner of fig. 2) between the Red 1.00 readings is 80 km, and 40 km halfway towards Merauke.

It was decided first to make a few test runs before considering a subsequent move of the transmitters. It turned out that the sea-bottom was extremely flat in these cross-overs; on both the 80- and 40-km runs, the depth did not vary more than a couple of metres about a general depth of 50 metres. Due to this exceptionally favourable circumstance, there was *in this case* no need for high accuracy of the Red hyperbolae between the two lanes of 1.00. Moreover, from the continuously observed Red decometers, it was evident that even the hyperbolae of 0.40 gave acceptable accuracy; the remaining distance in the longest cross-over was 40 km (2 $\frac{1}{2}$ hours at the ship's economic speed) and, bearing in mind that the lines of soundings along the Green hyperbolae themselves are accurately determined and that the bottom was extremely flat, it was concluded that the positions of the soundings along the Green lanes could be determined with acceptable accuracy by interpolation, according to time of run, between Red plus and minus 0.40 lane.

It is perhaps more correct to say that this method of « cross-over » was adopted as a *preliminary solution* and that it will be definitely adopted when no dangers to shipping are discovered in this sector. The work has not yet been finished, but so far no irregularities have been found. Should a single shoal be discovered, then it would be acceptable to determine its position by additional astronomic observations. The methods of position fixing at the disposal of a ship's navigator will in any case be less accurate than the fix of the surveyor. If more reefs and shoals should prove to exist, the decision can still be taken to move the chain as described earlier in this section.

18. — TRILATERATION

18.1. It has already been described how the length of a baseline can be determined from a lanecount, the known comparison frequency F and the known or adopted propagation speed V. The distance between two Slaves — for instance E (Red) and K (Green) in fig. 2 — cannot however be measured in this way. To measure this line, it would be necessary to make K or E a temporary Master station by moving part of the transmitting equipment from Merauke to one of these places; that would produce a temporary Red or Green pattern between K and E, wherein the lanes could be counted. The most likely propagation speed should then, of course, be used to compute the terrestrial distance between these two Slaves; in section 8 it has been shown that in a country like New Guinea, errors in V will certainly not exceed 1 part in 10 000 and will very likely be smaller.

In this way it is possible to measure the sides of a network of triangles or, even better, quadrangles.

> Transferring even a small portion of the Master's transmitting equipment would be no small undertaking in a country like New Guinea; it would therefore be simpler and certainly more economic to modify one of the Decca receivers (the one to be used for lanecounting) in such a way that a lanecount between the Slaves could be made directly, that is to say without moving any Master transmitting equipment. To this end, it would be necessary to synchronize Red temporarily to Green and to build-in other (or additional) multiplication factors in this receiver (9 for Red and 8 for Green or 0.75 for Red and 0.66 for Green).

18.2. In addition to these direct measurements of the length of the sides of triangles or quadrangles, the distance between the two Slaves can also be determined in the way described in section 11.

18.3. Although the two methods are not completely independent (among other things, both are affected by the same error in the adopted value of V) they would allow for some adjustment and comparing the two results would at least give a fairly reasonable indication of the accuracy.

This method of trilateration will be used in New Guinea to establish a geodetic framework over the whole of the area to be surveyed (fig. 1). The work will be undertaken as soon as the survey of the area of fig. 2 has been concluded.

19. — TRANSMITTING AND RECEIVING AERIALS

19.1. The transmitting aerials are base-insulated single masts, made up of sections of 3 m (10 ft). In New Guinea the Master aerial was 54 m (180 ft) and the Slaves 45 m (150 ft). Input power for all stations was 600 watts, the estimated output of the Master being 18 watts and the Slaves 15 watts.

Simple 7 $\frac{1}{2}$ m (25 ft) vertical aerials were used at the Slave stations for receiving the Master signal. At a distance of 200 m (600 ft) from the Master mast a similar receiving aerial was employed for the monitor station.

All these aerials have their associated radial earth wire systems (« groundmat »), of a length equal to the height of the mast; 100 radial wires, which can be buried underground, are used at the transmitters but only eight at the receivers.

19.2. The ship's receiving aerial consists of a single, isolated and approximately vertical wire from the mast-yard to the roof of the chart-room, the length of wire used on board H.N.M.S. *Snellius* being 9 m (30 ft). As two receivers with associated decometers were used for mutual control, two separate aerials were used, one on the starboard and the other one on the port side.

A similar receiving aerial of 3 ½ m (12 ft) was fitted on the much smaller boats used for wire-dragging, an operation whereby a long steel cable is towed at a pre-set depth underwater for the purpose of detecting shipwrecks and other very localized hazards which might escape discovery by echo-sounding.

In the still smaller sounding boats used in very shallow water operations, and for the Decca observations on land, whip aerials of about 2 ¾ m (9 ft) were used.

None of these receiving aerials needs a ground-mat.

For all receiving aerials, very good insulation is a strict requirement as is earthing of the equipment, which, however, is not difficult to achieve and to maintain with a proper installation.

Trials showed little difference in the strength and the signal received (at distances of 200 km and over) by the ship's aerial of 9 m and the boat's aerial of 3 ½ m; on the sounding-boat's 2 ¾ m whip aerial, however, only half the energy was picked up.

The ship's masts and rigging (subdivided by insulators) had no measurable directional effect on the receiving antenna.

No interference was caused by radiations from the transmitting aerial used for radio-communication purposes.

20. — RADIO COMMUNICATION

20.1. Although the synchronization between Master and Slaves is or can be made completely automatic, the smooth operation of a chain calls for some means of communication for the exchange of technical information, arrangements for the personnel, etc. Permanent radio links between the stations and the ship offer the best and simplest solution of this problem.

In New Guinea, for reasons of transportability and low power consumption, the communication transmitters had to be as light and small as possible and suitable for operation in the tropics. As only some of the station personnel had a telegraphist's certificate, radio telephony (R/T) was to be preferred to telegraphy (W/T). Because of the high noise-level, it was not expected that R/T would cover more than 200 kilometres under all conditions; at longer distance (up to some 700 km), however, very slow Morse was considered perfectly acceptable for the little and simple information that would have to be exchanged. It was therefore decided that combined R/T—W/T transmitters would be needed.

20.2. After careful consideration it was decided to purchase Redifon G.R. 49 transmitter/receivers for the stations and for the ship (fig. 22).

These transmitters can operate on four different frequencies in the range between 3.5 and 10 Mc/s (wavelengths between 85 and 30 metres) and the output is 50 watts.

This equipment complied completely with the above-mentioned requirements and even greatly surpassed them. Under normal conditions, distances up to 400 km over land as well as over sea could be bridged by day or night on the frequency of 3.5 Mc/s * using *telephony* all the time.

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* On the three other available frequencies, interference was sometimes experienced from other communication services in the area.


RADIO TELEPHONE
REDIFON
LONDON
SERVICE
CHANNEL
PHONES
PRESS KEY ON HANDSET TO TRANSMIT. RELEASE KEY TO RECEIVE.

Fig. 22.

For the purposes of refuelling, etc., the ship was occasionally away from the survey area and it was desirable to maintain contact with the technicians left at the stations; nearly always, good *telephony* contact could be maintained up to distances of 1 350 km.

The transmitters have now been in use for 1 ½ year and have remained unaffected by the high relative humidity which is generally 99 %.

It has not been necessary to resort to radio telegraphy.

21. — LINES OF SOUNDINGS, TRACK PLOTTER

21.1. Wherever one of the Decca patterns is sufficiently perpendicular to the coastline and/or to the lines of equal depth, lines of soundings (see section 1) are run along selected hyperbolae, at a suitable distance apart; it is of course not at all necessary that these lines should coincide with full hyperbola numbers. This method is sometimes called « homing » the ship — or other vehicle — on preselected hyperbolae. From an operational point of view the procedure is very simple, because the helmsman only needs to keep one decometer on a steady reading, which requires very little training.

For instance, in the sea area west of the meridian through the Master (fig. 2) the Green hyperbolae are suitable for this « homing » procedure. The lanewidth near the coast is 560 metres and the lanes gradually widen-out at sea. The geological formation of the sea bottom happens to be such that 560 m is a suitable lateral distance between the lines of sounding near the coast, and test runs showed that the gradual widening would be perfectly acceptable in the general sounding-plan. Wherever necessary, interjacent lines were run, for instance when irregular depth changes occurred in the echo sounded profile-lines and for local large-scale surveys.

It was therefore decided to base the general plan of soundings on « homing » along the full hyperbolae and to supplement this by interjacent hyperbolae whenever necessary for an exploration of the sea-bottom topography, which leaves practically no chance that dangers to shipping remain undiscovered. As these full hyperbolae have been already computed and plotted on the chart, this greatly facilitates plotting the lines of soundings.

Note: Negative pattern corrections (section 14) must be applied first, such that the corrected decometer readings become full numbers. Example: wanted chart hyperbola 221.00; pattern corrections +0.02; hyperbola to steer: 220.98.

Distance along a Green hyperbola can be determined by reading and plotting the Red decometers at fixed time intervals and additionally at any moment when a significant change of depth occurs; plotting is by graphical interpolation between the charted full Red lane-numbers. In those areas where the bottom was very flat, even this interpolation could be largely avoided as it proved to be much simpler to note the time of crossing of each full (or half) Red hyperbola and to divide the soundings according to time-of-run between these fixes.

21.2. In a comparatively large part of the coverage (fig. 2) this homing method cannot be used because the hyperbolae do not run in the desired direction. For instance when surveying the navigable rivers one has to follow the bends of these rivers; but also out at sea there may be many reasons why the ship's of boat's lines of soundings cannot be made coincident with the hyperbolae.

It is of course always possible to steer any desired course by taking simultaneous readings of the two decometers at any desired time-interval and plotting the position by graphical interpolation in the hyperbolic chart patterns. The objection to this method is that a constant compass-course does not necessarily nor often result in a straight line over the ground, because the force and direction of current frequently change from place to place. Operationally, it is therefore very difficult to follow any predetermined line on the chart; the difficulty being that any diversion from this line cannot be detected until both decometer-readings are plotted by graphical interpolation in the Decca chart patterns. Plotting takes time and as a result there is always a tendency with this method to overshoot the desired track to either side.

Predetermined tracks however can be followed in an easy and simple way when use is made of the Track Plotter. Fig. 23 shows a track recorded by this instrument on the river Thames. In the Track Plotter the decometer-readings are translated into related movements of a roller-mounted chart and a plotting pen, moving along axes lying at right angles. The hyperbolic Decca position-line patterns

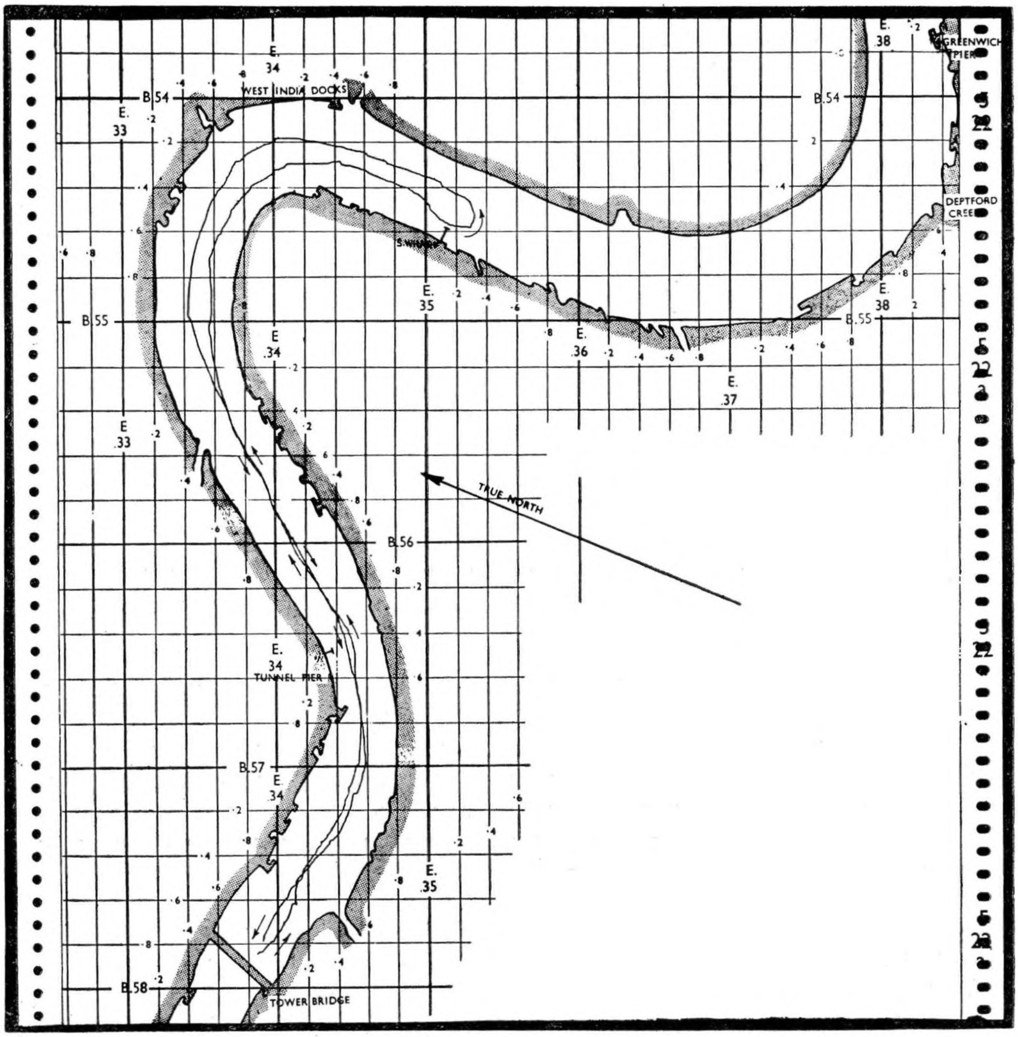

Fig. 23.

are represented upon the Track Plotter paper in a rectangular and rectilinear « inverse lattice » form. The pen indicates the position of the ship (or other vehicle) upon this lattice at any moment, tracing a continuous record of the track made good as the craft moves across the hyperbolic patterns. In hydrographic and other types of surveying these tracks are preselected lines, plotted on the hyperbolic Decca chart and then transferred to the rectangular coordinate system on the Track Plotter paper. The task of the helmsman is now to steer the ship in such a way that the pen follows the track, a procedure which needs little training.

The instrument provides for five switch-selected scales for both pen and paper separately, giving (as used in New Guinea) chart scales between 1/5 000 and 1/100 000. Further switching gives four possible orientations of the display, each displaced 90° from the next, and hence a rough approximation to a north — or heading-upward — display.

21.3. Elaborate tests have shown that the lag between the Track Plotter display (pen and paper) and the decometers does not exceed 0.25 millimetre (0.01 inch) at the scale in use.

21.4. For the New Guinea survey, two Track Plotters were provided, one for the ship and the other to be used on the smaller boat surveying the rivers inland.

22. — STATION PERSONNEL AND MAINTENANCE

22.1. The chain was initially set up and all geodetic computations were made under the supervision of the author of this paper, who also trained the staff of the survey vessel H.N.M.S. *Snellius* for a period of 6 months. Operationally the responsibility for the survey and for the Decca chain rests with the Commanding Officer of this ship, belonging to the Royal Netherlands Navy Hydrographic Office.

Once a chain has been set up and the necessary geodetic computations have been made, there is in principle little special training or technical knowledge required from the ship's officers in taking and plotting the decometer readings or in using the Track Plotter. As in any other kind of technical operation, however, it is highly desirable that the responsible staff people have a good insight into the general possibilities and limitations of the system as a whole. Only sufficient knowledge in this respect can guarantee ultimate accuracy and avoid neglect of different sources of small errors.

22.2. Technically, each of the three stations requires one radio mechanic on duty. Taking into account the remote locations, the daily working period of about 12 hours and the fact that in New Guinea each station has to provide its own electricity by means of 5.6 kw. Diesel generators, it was necessary to employ two mechanics at each station. As the monitor was located at the Master site, no extra personnel were required for this purpose. A specialist radio engineer supervised the whole chain. All these radio-technical services were provided by British personnel from the Decca Navigator Co.

22.3. Maintenance of the transmitters and receivers was the responsibility of the British radio personnel. Thanks to their good care and ability, there was not a single serious interruption in transmission during a period of 1 $\frac{1}{2}$ year of almost daily operation. Short interruptions through minor defects totalled less than 1 % of the total time of operation.

Before starting operations, it was estimated that the very severe climatic conditions would necessitate a thorough overhaul of part of the equipment after 1 $\frac{1}{2}$ year. However, after having been in operation for this period of time, the equipment did not show any signs of deterioration or wear and tear, and the expenditure of spare parts was below expectation.

This unexpectedly good performance — for New Guinea — may well be partly due to the fact that the stations were put into operation, for a few hours each day, whenever the ship was away from the area for refuelling or for the regular test periods.

23. — ECONOMY

23.1. The economy of the use of an electronic survey system is affected by a great many factors — most of them dependent on local circumstances — and it is therefore very difficult to make an assessment either in terms of time or in money.

The purchasing and maintenance cost of these systems is always considerable and evidently they will be more economical in regions where the detailed survey cannot be based on an existing triangulation network.

In this particular case, and in many other undeveloped areas where no terrestrial triangulation exists, it would be an enormous and extremely costly undertaking of many years' duration to cover the land area and the coastline by triangulation, and even then the position fixing for the detailed survey in the dense jungle and along the rivers would be a major problem. A geodetic framework of anchored buoys for the position fixing out at sea would have been extremely difficult and time-consuming to lay out, to measure and to maintain and in addition its inherent accuracy would have been very poor.

It should be noted that the main reason why the survey of this area has not been undertaken until now is that the problems of establishing a geodetic framework were considered to be practically insurmountable.

23.2. The ability to survey independently of visibility conditions is obviously one of the main advantages of an electronic survey system. As mentioned in section 1, nowadays there is a choice between several of these and the Decca Survey System was considered to be the most suitable for the type of survey that had to be carried out in New Guinea. A very important economic aspect of a *Decca* survey chain is the possibility of its simultaneous use by an unlimited number of observers on the ground and in the air as well as at sea; in principle this opens up the possibility of sharing the cost between different surveying agencies. Important also is the fact that any new user only needs an additional receiver which represents but a very small fraction of the cost of the whole equipment.

23.3. In New Guinea the chain was built and put into full operation in less than 12 weeks and from then on constituted a geodetic framework for all kinds of position fixing in an area of 250 × 420 kilometres (fig. 2). It is certainly not an exaggeration to say that these 12 weeks should be compared with the great many years that it would have taken to establish a framework by terrestrial methods, which even then — especially out at sea — would have been of poorer quality.

As the purchase price of this survey chain amounted to about one third of the *yearly* cost of the exploitation of a survey vessel in New Guinea, it can easily be seen that the gain in speed and efficiency is very considerable. It is very difficult to say over how many years the chain should be amortized; in this respect it should be recalled that after 1 ½ years' use under adverse climatic conditions, neither the transmitters nor the receivers showed any signs of deterioration and the use of spare parts was below expectation. Experience with other Decca survey chains makes it apparent that amortization over a period of ten years will be on the safe side.

24. — ACKNOWLEDGMENTS

It is impossible to mention by name all those who have taken part in this New Guinea survey project and have thus contributed to the final results. The author is in the first place indebted to the Netherlands Hydrographer, Rear Admiral Th. K. Baron van Asbeck, who is the authority responsible for the whole survey and who made it possible for me to carry out preliminary theoretical and practical studies. I learned very valuable lessons as a guest of the Royal Danish Navy when I took part in the hydrographic survey of Northern Greenland under Kommandör Axel Schmidt; this training was later supplemented in Tunisia under Professor P. Hugon of the French Hydrographic Service.

All the ship's staff and crew, under the command of Lt. Cdr. R. v. d. Oever, contributed to the final results; particularly I should like to mention the Chief Officer, Lt. A. Th. van Halder, who took an important part in the building of two of the stations, carried out some of the astro-observations and assisted me in the more complicated geodetic computations.

The author has had the benefit of extensive and valuable information from the staff of the Decca Navigator Co. Ltd.: particularly I should like to mention Mr H. G. Hawker and Mr C. Powell.

The information contained in the references and other publications has naturally been of great value.

Last, but certainly not least, I should like to express my thanks for the full and pleasant cooperation with the British radio team, formed by Mr. Hamitlon of the Decca Navigator Company. Their enthusiasm under difficult circumstances and their ability made it possible to operate the chain to high standards of accuracy and reliability. The installation engineer Mr. N. Ward, and the supervising radio engineer Mr. D. Loader, should particularly be mentioned in this respect.

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Reference should also be made publications by the Decca Navigator Co. Ltd., in particular the "Memo Plans" series of technical papers and the handbook "The Decca Navigator as an Aid to Survey".