POSITION FIXING SYSTEMS USED NOWADAYS AT SEA (*)

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1. — Introduction

The problem of position fixing at sea dates back to the times when, leaving his familiar shores, man ventured to conquer oceans and unknown lands.

After many tentative efforts, satisfactory solutions have been found for the mariner whose only aim was to transport body and goods by sea from one point of the globe to another. A correct application of the Archimedean principle, an adequate use of star positions, a magnetic compass, a good clock, nautical documentation will prove, with the help of God, to be sufficient.

However, the problem of accurate position fixing at sea, out of the sight of the coast — and by accurate I mean to within some ten metres — has only recently begun to be solved (some twenty years ago) by the use of radiolocation systems.

This accuracy is of a great interest to us who, as geophysicists, have to extend our knowledge beyond dry land in order to discover, describe and find the fine features or structures of the marine medium, of the bottom and even the submarine subsoil.

This need is made obvious by the number of radio systems used or projected which all enable us to reach, with more or less success, the much sought accuracy. I cite, according to the most recent information, *Hydrodist, Shoran, Hiran, Derveaux, E.P.I., Decca, Rana, Toran, Raydist, Loran, Omega, Transit,* and certainly there are others. We will, of course, not mention directional systems which range from *Consol* to *Navaglobe,* and include *V.O.R.* and other *Tacan* systems, for they do not meet our specific requirements.

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Faced with such a number of new systems, it will be easily understood that specialists have tried to make classifications here and there : one will suggest a discrimination between " ranging " methods, " hyperbolic " methods, and the other methods; another will adopt a criterion of range; a third will take the type of transmitted waves as a basis. The manufacturers emphasize the commodity of the on-shore and on-board installation, the robustness of their materials, ease of operation and low purchase prices.

Having applied some of these methods, and having been present at a number of tests and read many works on the subject, I consider that a multi-purpose and faultless radio positioning system has still to be developed, if not also to be designed. On the other hand, it is my opinion that the systems now used — be it by surveyors, prospectors, port engineers or wreck searchers — are good, whatever the methods used or the manufacturers' nationality.

In spite of this statement, it must not however be thought that trusting electronic engineers and their " black boxes " will be sufficient to obtain excellent results at the first attempt. For failing to take certain precautions, some users have experienced so much trouble that it would have been better if they had contented themselves with the old systems based on astronomic fixes. It follows that in the first instance we shall be interested in the study of the principles of radio positioning systems, and then we shall examine what has to be done to turn them to the best advantage and finally we shall see whether in the future better solutions could be brought to our problems.

2. — Principle of distance measuring systems

The principle of all radio positioning systems based on distance measurement — the only ones accurate enough to be considered here — is based on the following relation :

$$D = V(T_1 - T_0) \qquad (1)$$

where:

D = the distance between a point A of a known position and a point B whose position is to be determined.

V = the velocity of propagation of radio waves along path AB.

$T_1 - T_0$ = the time needed for these waves to cover this path.

3. — Comments on the fundamental relation

Knowing that V is about 300 000 kilometres per second, we note immediately that the time intervals have to be measured to within 0.03 microseconds in order to determine the distance to within about ten metres.

If D is approximately 200 kilometres in length (or 100 km there and 100 km back), it is necessary that the velocity of propagation should be known to within 1/20 000.

Now that we know the accuracy required it remains to examine how to obtain it.

a) ***Propagation velocity***

In relation (1) the velocity of propagation V is not dependent on us: its *in vacuo* value is now well known; i.e. 299 792.5 ± 0.4 kilometres per second.

In practice, the velocity of propagation depends on the refractive index of the atmosphere and above all on the conductivity of the surface with which the waves propagated are in contact.

Fortunately, over the sea, a fairly homogeneous medium of good conductivity, velocity veriations only reach about $\pm V/30\,000$ for a value of 299 690 km per second.

Over less favourable surfaces, ranging from salty marshlands to bare rocks, V may decrease by more than 1 000 km per second, i.e. about $V/300$. Probable values may be determined, of course, but these will often be faulty, since rapid and unexpected variations may occur : a rain squall falling on a dry surface, or the tide covering and uncovering a long and sandy shore have considerable effect on the velocity to be expected.

Moreover, anomalies occur at the boundaries of areas where the ground conductivity is not the same; these anomalies depend on the difference in the electrical characteristics of each area, and on the angle between the directions of wave propagation and boundaries. Thus the most unfavourable case is when islands are to be found between the work area and the transmitters; thus entailing composite paths crossing several coast lines.

In order to guard against these propagation anomalies, maximum care must be taken when setting up and checking the systems.

In particular:

— Transmitting stations must, if possible, be placed in the close vicinity of the shore. Moreover, in the hyperbolic methods which will be discussed later on, synchronization paths must be made over sea, or at least over a homogeneous surface of constant characteristics.

— An accurate and extended calibration must be made before any operation. In addition, frequent checks of the initial adjustments must be made.

— A fixed monitor station may be profitably used but too much importance must not be given to its indications, unless it is located in the very centre of the work area on an isolated rock, lighthouse or platform, and this is not often possible.

b) ***Measurement of transit time $T_1 - T_0 = It$***

It has been seen that, in order to obtain the accuracy required of our systems, the transit time of radio signals has to be known to within 0.03 microsecond. In the laboratory we are able to estimate accurately such time intervals since the phenomenon starts and finishes under our eyes. But with radio positioning these two events occur at a great distance from one another, and the measurement of the time interval *It* between them can obviously only be made in two ways:

i) The clock used for this measurement is placed on board, and we shall have the transmitting instant T_0 very easily, but the signal must be sent back from on shore to enable us to note the instant T_1 of its return.

In this case, therefore, we have to use an outward and an inward path, after reception and re-transmission at the fixed point situated at distance *D* which is to be measured. The systems using this "mobile clock" are called "direct measuring" or "ranging" systems (the lines of position they supply are circles). All of them can be used simultaneously only by a limited number of ships (in most cases by only one).

ii) Alternatively the same clock is placed on shore and thus we shall not be able to determine T_0 on board. In this case, we must have two fixed stations, A and B, transmitting at instant T_0 synchronized signals, which are received on the mobile at instants *Ta* and *Tb*, the interval between them being measured easily. Applying relation (1) we shall have :

$$D_a = V\,(T_a - T_0)$$

$$D_b = V\,(T_b - T_0)$$

whence:

$$D_a - D_b = V\,(T_a - T_b).$$

We obtain a line of position defined by the difference between two distances. This line will be one of the hyperbolae having foci A and B. The systems which use this "fixed clock" are called "hyperbolic". They can be used simultaneously by any number of ships; but most of them require the use of additional signals allowing the elimination of ambiguity. As a rough comparison we may say that our clock should include two, or even three needles turning at different speeds, the user being able to know their position at any instant.

In these systems, one of the transmitting stations, for example A, is called the "free" or "master" station, the other, B, is called the "slave". Line A B is called the "baseline", its prolongations are the baseline "extensions". Two transmitters make up a "pattern"; the area between two adjacent hyperbolae of equal phase is known as a "lane".

Another method is to leave A and B "free"; the transmitted signals are not synchronous but the phase difference is measured at a fixed receiving station, from which this information is re-transmitted to the mobile, which takes this information into account for evaluating interval $Ta - Tb$.

From the above it may be seen that, whatever the method used, at least two transmitting stations have to be used to obtain only one circular or hyperbolic line of position. Since the mobile's position is, of course, necessarily determined by the intersection of at least two of these lines of position, it will be essential to increase the number of on-shore installations, and to accept the resulting consequences. In addition, in order to obtain the only information of actual interest, i.e. a distance D for ranging systems, paths equal to $2D$ must be taken into account, and for hyperbolic systems paths longer than $2D$. As the error due to approximations of the value of wave velocity is proportional to the length of the paths, as stated above, it is evident that our present systems are not perfect.

4. — Type of signals

The information given by signals transmitted in radio positioning amounts to this : " By my clock, it is exactly N microseconds". This "hourly pip" is either received on shore and re-transmitted to the ship in a ranging system, or in hyperbolic systems received by another station and also re-transmitted.

There are several ways to convey this information, but imperative considerations relative either to the wave propagation or to the type of electronic component units always limit the choice of way. Consequently, this selection will be forced upon us through considerations of range, of transmitted frequencies and also, to a minor extent, of the method used.

These pips can be transmitted by:
— pulses;
— continuous waves (either permanent or time-shared);
— composite waves.

a) Pulses are relatively easy to build up, at least for wave lengths below 200 metres. Above this level difficulties arise (steepness of leading edge, pass-band, etc.) with which we shall not deal here. This transmitting method permits the reduction of the number of frequencies to be radiated, and high peak power with a rather low power supply can be obtained. Additional codings allow a very flexible and reliable reception through lockings and elimination of ambiguity.

Pulses are necessarily used in ranging systems using responder beacons, such as *Shoran, Hiran, E.P.I., Derveaux.*

b) Pure continuous waves were the first to be used in radio positioning methods, since they are very convenient: their transmission is obtained easily with high stability; their frequencies can be directly subjected to the four basic arithmetical operations; a considerable amount of information can be obtained by analyzing their frequency phase characteristics. Such a "redundancy", as it is called by technicians, allows voltages to be integrated, whence an excellent reception in spite of high level radio noise.

However, the fact of taking into account the phase, which is only measured to within one cycle, will entail ambiguity. It is desirable, and often necessary, to eliminate this ambiguity; the number of transmitted frequencies must therefore be increased.

On the other hand, interferences with the sky wave occur at some distance from the transmitters, as will be seen later. This makes this type of transmission unworkable at great range.

Another solution is to profit by the redundance inherent in the pure continuous waves and to transmit them according to time-shared sequences, storing in memory previous information : a smaller number of frequencies is therefore sufficient, and at the same time problems arising from station installations and spare parts are simplified. Unfortunately technical complexity is increased, and instability of the memories is always a risk.

Systems using continuous waves, whether permanent or time-shared, may be either circular or hyperbolic according to whether or not a transmitter is placed on the mobile. Most of the known systems, in alphabetical order, *Decca, Lorac, Rana, Raydist, Toran,* will be found in this group.

c) In composite methods, either a carrier wave can be modulated as it is the case in systems derived from the TELLUROMETER (*Hydrodist, Cubic,* etc.) or a pure continuous wave is transmitted within a pulse, as in the *Loran C* system. In the latter case two kinds of information with different characteristics are transmitted in turn: measurements can then be made using first the leading edge of the pulses, then the phase of the continuous wave within the pulse, which cleverly resolves the problem of eliminating ambiguity.

5. — Paths of wave according to frequency — Power and range

The use of relation (1) is, of course, only justified if we know the path which the signal from the transmitter to the receiver follows at velocity V.

If the type of paths were uncertain, any radio positioning based on these principles would be impossible. Difficulties arise, however, since the behaviour of the waves depends on their frequency and on the characteristics of the reflecting layers surrounding the earth in the ionosphere. (It is well known that there are several of these layers situated at altitudes varying with the different hours of the day and with the seasons; some of them exist only in daylight, others only at night).

Let us first recall that technicians discern two principal modes of propagation, at least for the frequencies that we are using:

— by ground waves,
— by sky waves or ionospheric C waves.

Ground waves are, in their turn, subdivided into three types :

— direct waves D,
— ground-reflected waves R,
— surface waves S.

Wave D follows a straight line between the transmitting and the receiving antenna. Its range is therefore limited by the curvature of the earth, and depends above all upon the altitude of the aerials at both terminals. In normal conditions, the distances reached exceed the purely optical ranges by about one third. It will be noted that the velocity of wave D is independent of the characteristics of the earth when not in contact with the ground : it is then only a function of atmospheric variables and can be computed with accuracy from meteorological data.

Wave R follows two rectilinear paths, one before, one after reflection. Let us simply note that this wave may cause trouble when using very high frequency systems.

Wave S follows the curvature of the earth.

Finally, according to the circumstances, wave C may pass through the ionosphere or be sent back towards the earth by the ionosphere.

In all cases — and this is essential in radio positioning — the paths used for measurements are in the vertical plane passing through the transmitting and the receiving stations.

As previously seen, the predominance of one of these waves over the others depends above all on the frequency transmitted. For each given system the choice of this frequency is based on considerations of range: the minimum power to be radiated is then practically imposed.

For small distances, i.e. up to the visual limit and even slightly beyond, the most advantageous will be very short waves of less than 10 metres (of frequencies higher than 30 Mc/s); the surface wave is rapidly attenuated, and measurements are made by means of wave D having a rectilinear path.

Transmissions may be more or less directional, the powers required will be low; wave velocity will be well known: *Shoran, Hiran, Derveaux, Hydrodist* systems use this frequency band with signals of the pulse type. They supply distances directly and the number of users is limited.

If a greater range is to be obtained, it will be necessary to use a medium wave band between 100 and 200 metres (3 to 1.5 Mc/s). With radiated power of the order of one kilowatt, theoretical ranges of several hundreds kilometres will be reached. Actually, efficient ranges will be much lower, since the sky wave reflected by the ionosphere starts to interfere with the surface wave at rather short distance from the transmitter, chiefly at night, and it is therefore difficult to make use of the signals received. Amongst the systems using such a frequency band, let us mention *Decca* (*Hifix, Seafix*), *Lorac* (*A* and *B*), *Rana* (*H* and *HS*), *Toran* (*3P* and *3G*), *Raydist* (*DM*). They usually transmit permanent or time-shared signals of continuous waves which supply hyperbolic lines of position, or circular lines in a certain version (a transmitter on board). The number of users is not limited except with the American *E.P.I.* which transmits pulses on 2 Mc/s.

For distances of several thousand kilometres, the use of long waves — 3 000 metres and above — is imperative. Radiated power will be of at least 100 kilowatts; transmitting aerials should be of great size. Special devices will allow — as long as the surface wave is detected — the elimination of the sky wave which, at the earliest, is only received 30 microseconds later. At still greater distances, further measurements may be made by using the successive hops of the sky wave between the earth and the ionosphere. The accuracies obtained — a few hundred metres — are obviously insufficient for our requirements, but it is good to know that such systems (*Loran C, Omega*) exist since they may be used as a makeshift for rough preliminary work, i.e. in certain areas when the use of a more accurate system is not possible (for instance for investigating banks located far offshore).

Due to this behaviour of the waves according to their frequencies, it will be noted that an increase in the radiated power does not necessarily entail an appreciable increase in the effective range. However, extra radiated power is often welcome, above all in the areas and at seasons in which the background noise is considerable and risks muffling the signals received.

Finally, it will be noted that the choice of frequencies is not entirely free; these have to be within the frequency bands allotted to radionavigation and radio positioning by international agreements.

6. — Advantages of systems — Calibration — Errors

Radio positioning systems are measuring instruments and, as such, they should have qualities, which once evaluated will allow calibration. In practice, however, errors will still affect the measurements, and it is necessary to know their magnitude.

ESSENTIAL CHARACTERISTICS OF THE SYSTEMS

Sensitivity: In a given variation of the size being measured the greater the displacement on the system's indicator, the more sensitive is this system.

Practically, all systems have this advantage built-in. Everything else being equal, it will be recalled that to appreciate a 10-metre variation in the distance measurement a time evaluation to within 0.03 microsecond is required.

Repeatability: The higher the agreement of the results, under different conditions of operation but with basic factors of equal value, the greater is the repeatability of the system. It will be seen that such a quality is essential; without it, it would not be possible, for instance, to return with certainty to either a small submerged feature or an object whose position had been determined during previous investigations.

Repeatability is likely to be affected by instability inherent in the installation, by the influence of atmospherics and by interference due to other radio transmissions, and finally by changes in the conditions of wave propagation.

With regard to internal factors and atmospherics, manufacturers must set up circuits that are as stable as possible, choose the best radiated power, and give their receivers the maximum protection against unwanted noise. They usually succeed fairly well in doing so, but some old models require frequent checking. It must be kept in mind that the stability of "memories" is not reliable in time-shared systems, even though these are of recent development.

As to variations in wave velocity, we must put up with these. As already seen, a monitor receiver can give useful information since it allows the elimination of certain *random errors.*

CALIBRATION — RELATIVE ACCURACY AND ABSOLUTE ACCURACY

A system once its sensitivity and repeatability have been proved may, and must, be calibrated, i.e. its information should be compared to that supplied by a more accurate instrument. Such calibration is usually made by determining the position of the receiving station at sea by means of sightings from theodolites placed at sites with known geodetic coordinates: the accuracy of such determination is of the order of a metre. For each pattern, deviations between either distances or phases (according to the type of system to be calibrated) are inferred from the true values and from the values read at the same time on the indicators of the receiver on board. Such deviations will enable us to evaluate the *relative accuracy* of the measurements; the graphs showing these "errors" *versus* the distance or the number of hyperbolae will yield the calibration curve for each pattern. Later on these curves will be used for eliminating *systematic errors* not only in the calibration area but also beyond this area, that is out of sight of land. It must be admitted that such an extension is nothing but an often risky extrapolation when the system used supplies only two lines of position. Consequently, the French Hydrographic Office always uses three patterns in surveying, thus defining three lines of position whose intersection forms a small triangle or "Cockhat". The shape of this triangle alone enables us to know whether the results obtained in the calibration area may be adopted for its extension seaward without new corrections. In addition, the size of this triangle yields very useful information on the *absolute accuracy* of the system.

For information, here are two performances referring to three types of circular and hyperbolic systems used in my department. They are inferred from several thousand observations made in widely differing regions and conditions:

— relative accuracy better than 5 metres,

— absolute accuracy better than 10 metres, up to the limit of radio range (200 kilometres).

I think that both these performances clearly show what the user may expect from any modern radio positioning system.

Before leaving this very important question of calibration I must point out that such notions as "standard deviation" or "root mean square error", so dear to certain authors, seem to be far too theoretical and that their application often leads to optimistical but not always objective evaluations.

It remains to be stated that, whenever possible, the crossing of the baseline extensions in hyperbolic systems supplies a rapid control of the pattern stability, but this method is never as reliable as a systematic calibration.

7. — Practical Arrangements — Form and analysis of the results

The site of shore stations will be chosen, as far as possible, with a view to obtaining the best possible conditions, i.e. those where all wave paths are only over sea. I am sorry to say that I have never actually been able to satisfy such conditions, for, all things being equal, it is essential that in the greater part of the working zone, the intersection of position lines be as good as possible. In practice the "geometry" of the siting is almost imposed by this condition, particularly with not very flexible systems composed of one single master station and of two slaves. It would be best to take account of the disturbing effect due to the proximity of electric or telephone lines, trees, various obstacles, rocky cliffs, sandy shores, etc. Land access facilities and, in certain areas, the cooperation of proprietors of estates will have to be considered in our choice.

To the credit of manufacturers it should be stated that for the past few years they have been making a great effort to facilitate our task in manufacturing more compact and lighter equipment and power supply, and securing more automatic and reliable operation.

Those who have had to work in somewhat difficult areas will be of the opinion that these "logistic" and technologic qualities are not of minor importance.

To make convenient use of the results, it is necessary, whatever the system used, to have available "sheets" upon which hyperbolic or circular lattices are plotted. The choice of the projection to be adopted will be made with discrimination if we wish to maintain for the plotting the accuracy level so hardly obtained for the measurement. The projection system in which the geodetic positions of the transmitting antennae have been determined will often be used. However, if its extension over sea, offshore, entails too considerable variations of the linear alteration there should be no hesitation in adopting a particular projection system computed for the working area. I shall not deal with geodetic surveys, whose study does not find its place here, but it will be noted that in order to obtain the accuracy required for radio location, the positions of transmitting antennae will have to be known to within a maximum error of 1 metre.

In particularly difficult conditions, an inverse method, consisting of determining these positions from observations yielded by the radio system itself, may be tried; it should be understood that such method will be used only as a last resource.

The computation and plotting required for the drawing up of sheets may, of course, be made manually: such operations are long and tiresome and mistakes may be made. A programmed electronic computer, associated with a coordinatograph, will do this work within a few hours, but errors remain possible.

With regard to the form in which the receivers supply the information, manufacturers give us a very large choice resulting from their recent efforts to offer us additional units. In addition to phasemeters or direct-reading meters which are essential, it is the author's opinion that continuous analogical recorders are necessary: they allow observations to be averaged and to be kept for further and more elaborate analysis, or for checking. They also entail a reduction of the personnel studying the information. Digital recorders are convenient for direct mechanical analysis. They may also be connected with units of the same type which simultaneously record the other information constituting the main object of the survey (bathymetry, gravimetry, geology, magnetism, etc.).

A right and left indicator placed in front of the helmsman will be very useful for steering along the hyperbolae or circles of a network.

Finally, if we can afford it, we shall purchase a track plotter, or even one or several computers which will give our position directly in geodetic or even geographic coordinates.

It is superfluous to mention that all these extra facilities do not in the least increase the accuracy of the information finally obtained; they might even reduce it since the overall instrumental error increases whenever an additional unit is added to the units in series used to obtain information.

8. — Characteristics of the main systems

Considering the variety of the systems in use at the present time, it will not be possible to describe them all; technicological details on one of them would be of no interest.

I believe it interesting, however, to mention the basic characteristics of the main systems known to me and in use at the present time. The figures shown arise from either personal experience, specialized work or manufacturers' notes; the are only given for guidance, are often optimistic and apply to average work conditions.

The table, given at the end of the article, shows for each type of system:

— the manufacturer's nationality;
— the central frequency, in kc/s, of the transmission band;

— the type of signals (continuous, time-shared, pulse);
— the range of the ground wave in nautical miles of 1 852 metres;
— maximum and minimum accuracies in metres;
— the presence or absence of a method of eliminating ambiguity;
— the limited or unlimited number of users.

The power radiated has not been indicated; it is not an essential characteristic since it is always sufficient for obtaining the range indicated. It should be borne in mind, however, that this range may be considerably reduced at night due to interference between the surface wave and the sky wave.

The classification has been made taking into account both the circular and hyperbolic type of the lines of position supplied by the system. Composite systems determine either circles if one transmitter is on board and the other on shore, or hyperbolae if both transmitters are on shore. When in a circular version composite systems may only be used by a limited number of users.

Within each group an order of increasing range has been adopted.

9. — Foreseeable development — Conclusion

From what has been stated above, it would seem that in order to find the radio positioning system or systems meeting our requirements we have only to choose from among the many offered. However, we would prefer, firstly, not to have to set up two transmitters in order to obtain a single line of position, for whose rather difficult determination the waves have to cover a distance at least twice as long as the distance to be measured. In addition, we would prefer not to use systems of types differing with the range we wish to obtain. Finally, we would also like to be no longer compelled to have to erect our antennae at the nearest possible sites to the coastline of the areas to be surveyed. In other words, we would like to have a perfectly stable system that is simple, multi-purpose and worldwide.

The first goal may be reached in the near future without upsetting the principles of the now classical methods too much. The difficulty which arose with regard to time measurement came from the fact that the clocks used were actually "intervalmeters" and not true "time-pieces".

Let us assume that two "clocks" in strict synchronization are available: we place one on shore and let it transmit "pips" at pre-fixed times; the other clock is on board; the latter will enable us to measure directly the transit time of signals, since on our ship we know the exact moment at which they were transmitted. Thus we obtain one distance with one transmitter only. A third clock synchronized with both the previous ones and also placed on shore in another site will yield a second distance in the same manner.

Perfect and continuous synchronization is impracticable, of course, but if our timekeeper at the transmitter does not deviate by more than one microsecond per day from the similar clocks ashore, we shall, during these 24 hours, measure the distance with an error lower than 300 metres. One microsecond per day means an accuracy of one second in 3 000 years. This may possibly be reached with our present atomic resonators. A ten times higher stability (one second in 30 000 years) is expected to be reached and even exceeded. Distance errors in radio-positioning will then become lower than 30 metres per day.

With regard to achieving a universal and multi-purpose system, this will undoubtedly take a longer time but the theoretical solution has already been found: it will suffice — if one can say so — to launch several satellites — 24 according to an American project — equipped with synchronized clocks. I am afraid my career as an hydrographic surveyor will be finished before these new systems have become current, but I feel certain that my successors will have the pleasure of taking advantage of them.

In conclusion, this is the wish I venture to make for them.

Characteristics of the principal radio positioning systems

Name	Nation.	Freq. in c/s	Signal type	Range	Accuracies	Amb. elimin.	Users
a/ HYPERBOLIC							
RANA H	Fr.	2 M c/s	C. W.	200	5 - 10	yes	multi
TORAN 3 G	Fr.	do.	do.	200	do.	yes	do.
LORAC A & B	U. S.	do.	do.	200	do.	no	do.
DECCA HYDRO	G. B.	100 K c/s	do.	200	10 - 150	no	do.
LORAN C	U. S.	do.	Pulsed & C. W.	1 200	30 - 300	yes	do.
b/ RANGING							
HYDRODIST	South Africa and G. B.	3 000 M c/s	Pulsed	visual	1 - 5	yes	1
SHORAN & HIRAN	U. S.	300 M c/s	Pulsed	do.	5 - 10	yes	1
DERVEAUX	Fr.	250 M c/s	Pulsed	do.	do.	yes	10
RAYDIST D. M.	U. S.	1.5 to 5 Mc/s	C. W.	200	5 - 30	no	1
E. P. I.	U. S.	2 M c/s	Pulsed	400	15 - 60	yes	1
DECCA LAMBDA	G. B.	100 K c/s	C. W.	400	10 - 100	yes	1
c/ COMPOSITE							
HI-FIX A	G. B.	2 M c/s	C. W. Seq.	200	5 - 10	no	multi if hyper.
HI-FIX B	G. B.	do.	do.	do.	do.	yes	do.
RANA-NEPTUNE	Fr.	60 to 100 Mc/s	C. W.	30	5 - 10	yes	multi