RADIO POSITION-FIXING SYSTEMS IN FRENCH HYDROGRAPHY

by A. Brunel,
Ingénieur Hydrographe en Chef de 1re classe

The hydrographic utilization of radio navigational systems was investigated by hydrographers throughout the world as soon as the war ended; research, testing, and development took place for the purpose of designing radio position-finding equipment for hydrographic use. In some cases, activity was restricted to the adaptation of existing radio navigational equipment (such as Decca), but in others, the problem was approached from an entirely new angle.

Actually, a different standard of performance is required for surveying equipment as compared with navigational equipment. It need not be emphasized that a higher degree of accuracy, as well as the accuracy actually obtained, are required. Although, within sight of land, results may be compared to those of conventional geodesy, out of sight of land three independent position lines are needed — an indispensable requirement for ascertaining accuracy without resorting to excessive extrapolation. Moreover, even though the equipment may not have to be mobile, it must be fairly easy to transport since the ground stations must be resited according to the exigencies of the survey. The maximum amount of flexibility in the choice of sites is therefore desirable, and the latter should not be subjected to an inordinate number of specifications. On the other hand, the maximum accuracy of which the equipment is capable may, if necessary, be regarded as not being an urgent operational requirement, and an instantaneous approximate indication as sufficient for the satisfactory completion of field operations.

Another advantage is that the position lines supplied by the equipment be simple enough for them to be plotted by means of the facilities available to the survey group. It occasionally happens that the exact coordinates of the antennas are obtained with a certain amount of delay, and it may be necessary to resite the stations during operations. If plotting of the grids is a lengthy and delicate procedure, operations will be delayed.

Among the various systems proposed, two methods have finally been retained :

The first is a pulse method in which distances are measured, to points whose positions are known, by means of the time of travel of very brief radio pulses. The pulses are radiated by the mobile and received by responder beacons, which retransmit the pulse back to the mobile.

The second method makes use of the variation with distance of the phase of a radio wave, which varies by 2 π each time the wave travels over a path in space equivalent to the wavelength. In the phase method, the ultimate observation is the difference in the distances to two known points, which determines a locus of the position. On the reference ellipsoid, this locus is analogous to a hyperbola, called the « geodetic hyperbola ».

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The pulse method, as we know, was used in developing American equipment, i.e. Shoran and EPI.

A similar apparatus exists in France, called the Derveaux Radionavigator, which measures distances between the mobile and three responder beacons.

An interrogator is installed on the ship; over a brief time interval it successively triggers the three responder beacons by means of the transmission of very short wave trains (0.5 μs) according to a « code » consisting of series of pulses separated by 2 μs, 3 μs, or 4 μs, depending on the responder triggered.

Each responder selects the appropriate separate signal and transmits in turn a short wave train which is also coded and is received by the interrogator.

The latter discriminates between each coded reply and directs it towards an appropriate separate circuit which enables determination of the time interval between interrogation and response, hence the distance between the interrogator and the corresponding responder. Measurement is reduced to that of the phase difference between two sine waves respectively defined by the interrogating pulse and the responder pulse.

The answering pulse is first matched by hand with a reference mark, which triggers a servo mechanism ensuring later the measurement of the phase difference. A display system supplies a direct and continuous dial reading of the corresponding distance, regardless of the movements of the mobile.

Interrogation takes place on a frequency of 250 Mc/s; responses are on a 240 Mc/s frequency, in order that beacon response may be differentiated from a possible echo from a passive target. Owing to the high frequencies used, the range of the equipment is limited in principle to visual range, increased however by about 30 %. The radiated power is 5 kilowatts, which ensures, provided the visual range, increased by 30 %, is sufficient, the measurement of distances up to 150 km.

The heavy and delicate part of the equipment is the shipborne apparatus, whereas the responder beacons are light in weight (max. 150 kg) and can be broken up into 30 kg sections, thus enabling them to be carried on a man's back. This is a considerable advantage on coasts where communications are poor.

Position-finding accuracy during trials amounted to about 30 metres over distances of the order to 100 km. It should be pointed out, however, that the equipment is not yet in current use, and that it may be premature to make any definite statements as regards expected performance.

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The phase method has been used in France with two systems : Decca, and especially Rana, which will be the main subject of discussion in this article.

With regard to Decca, use has been made of « mobile » chains especially designed for hydrographic surveying, and which operate along the same principles as navigational chains, but with two position lines only. This equipment was utilized during two fairly extensive surveys : one carried out in 1951 off the mouth of the Gironde, and the other off the coast of Morocco near Casablanca, in 1952.

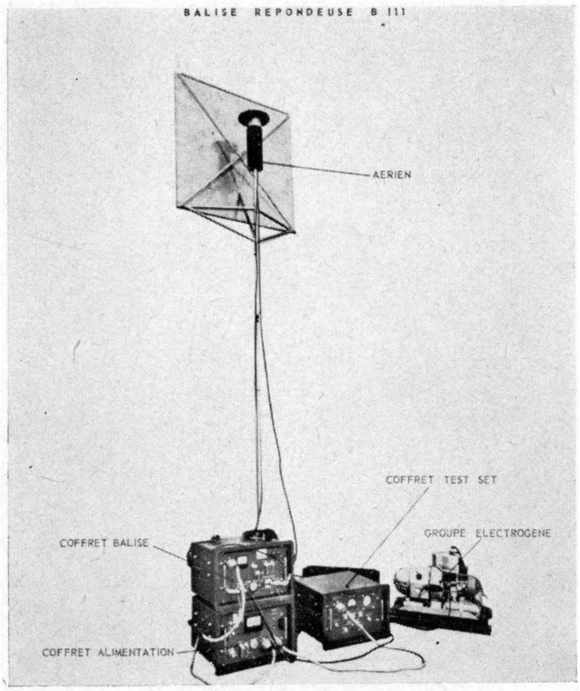
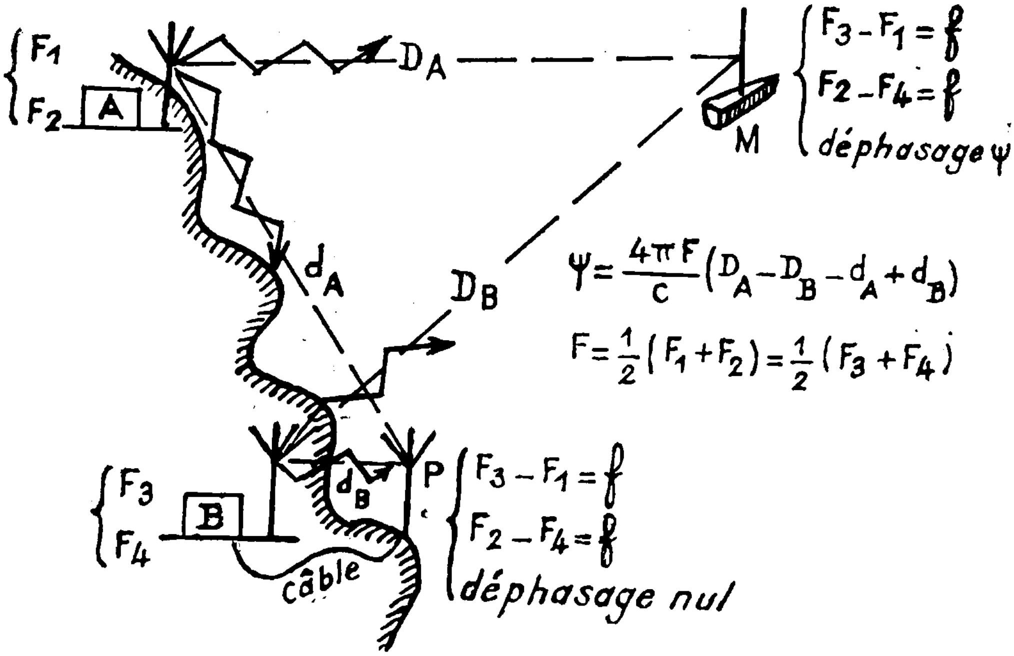


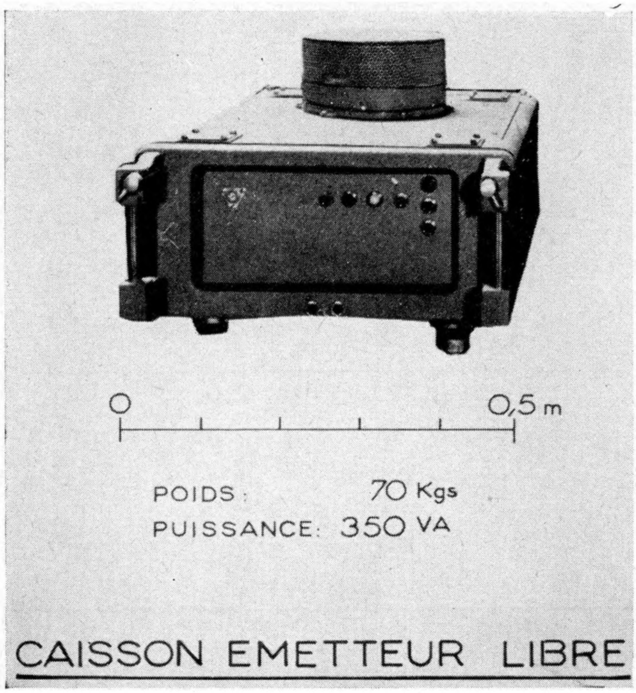
Fig. **1.**

Responder Beacon.



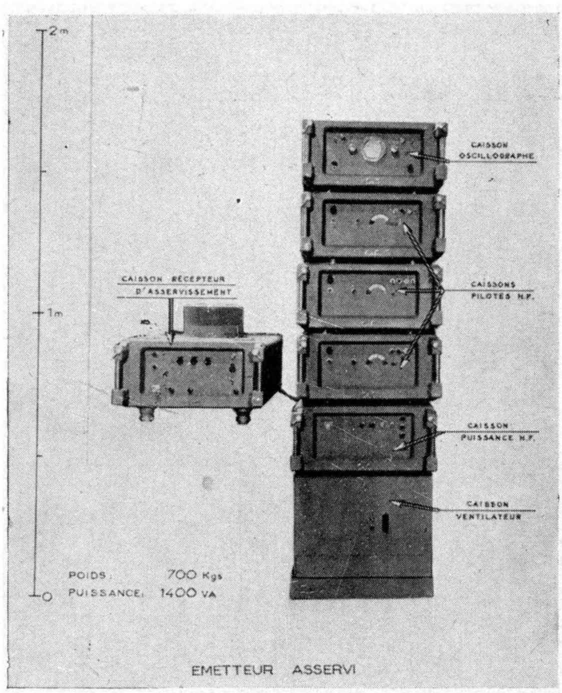
F1
F2
A
DA
M
F3 - F1 = f
F2 - F4 = f
déphasage ψ
dA
DB
ψ = 4πF/c (DA - DB - dA + dB)
F = 1/2 (F1 + F2) = 1/2 (F3 + F4)
F3
F4
B
dB
P
câble
F3 - F1 = f
F2 - F4 = f
déphasage nul

Fig. 2.



0
0,5 m
POIDS: 70 Kgs
PUISSANCE: 350 VA
CAISSON EMETTEUR LIBRE

Fig. 3.



2 m
1 m
0
CAISSON OSCILLOGRAPHE
CAISSON RÉCEPTEUR D'ASSERVISSEMENT
CAISSONS PILOTES H.F.
CAISSON PUISSANCE H.F.
CAISSON VENTILATEUR
POIDS: 700 Kgs
PUISSANCE: 1400 VA
EMETTEUR ASSERVI

Fig. 4.

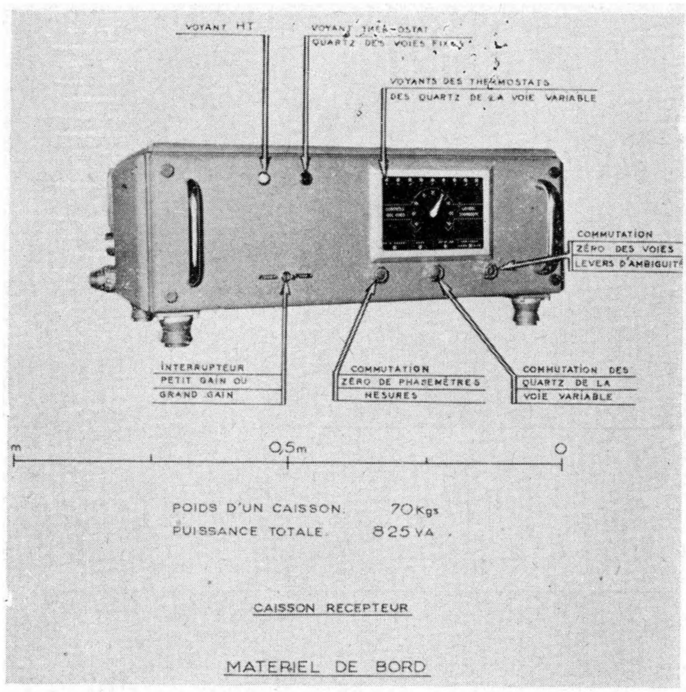

VOYANT HT
VOYANT THERMOSTAT
QUARTZ DES VOIES FIXES
VOYANTS DES THERMOSTATS
DES QUARTZ DE LA VOIE VARIABLE
COMMUTATION
ZÉRO DES VOIES
LEVERS D'AMBIGUITÉ
INTERRUPTEUR
PETIT GAIN OU
GRAND GAIN
COMMUTATION
ZÉRO DE PHASEMÈTRES
MESURES
COMMUTATION DES
QUARTZ DE LA
VOIE VARIABLE
0,5m
0
POIDS D'UN CAISSON. 70Kgs
PUISSANCE TOTALE. 825VA
CAISSON RECEPTEUR
MATERIEL DE BORD

Fig. 5.

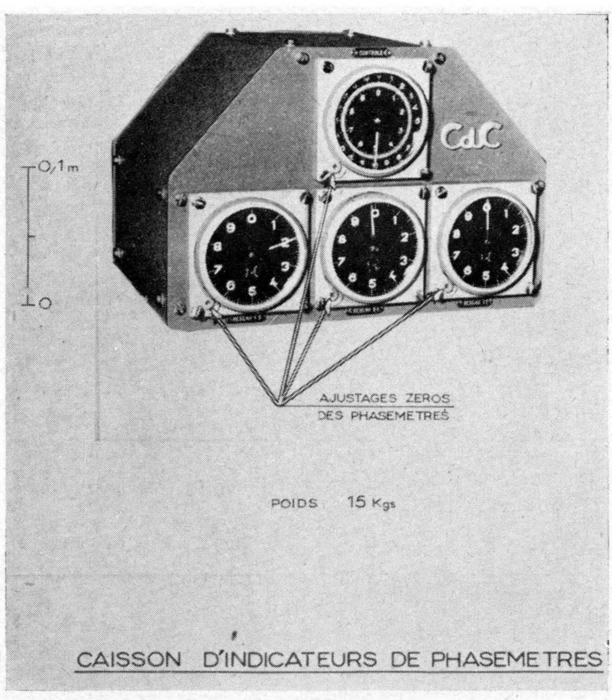

CdC
0,1m
0
AJUSTAGES ZEROS
DES PHASEMETRES
POIDS 15 Kgs
CAISSON D'INDICATEURS DE PHASEMETRES

Fig. 6.

In both cases, the distance between the master transmitter and the slave transmitters was about 50 km, and work could be carried out up to 100 km offshore. Operation of the equipment was satisfactory owing to the long experience of the makers and the careful design of the instruments. Such qualities are of course indispensable for the achieving of satisfactory results with technically complex equipment of this type, since it is a well-known fact that it involves a series of frequency multiplications and divisions during which all three phases, even though they need not be retained, nevertheless require a similar type of modification.

Inconvenient features of the Decca survey chain are, first, the relative lack of mobility of the ground stations, which may thus interfere with its use on certain types of shoreline; secondly, a certain rigidity in the siting diagram, which requires that the baselines be 120° apart for optimum conditions to be obtained; and finally the absence of a third position line, lacking which nothing is known regarding the accuracy obtained far from shore.

Rana is particularly well adapted for hydrographic surveying, whether from the aspect of the accuracy that can be expected or of the flexibility of the possible types of siting diagrams (1).

A Rana chain consists of three *independent* pairs of transmitters each defining a geodetic hyperbola, or the locus of the position to be fixed.

Each pair consists of a *free* transmitter A radiating two frequencies F_1 and F_2 over a single antenna, and a *slave* transmitter radiating two additional frequencies F_3 and F_4 likewise over a single antenna. These frequencies are such that :

$$F_3 = F_1 + f$$

$$F_4 = F_2 - f$$

This condition is strictly and automatically achieved by means of a servo device comprising an antenna P placed in the vicinity of the slave transmitter (to which it is connected by coaxial cable) at distances d_A and d_B from the free and slave transmitters.

At the receiver P, frequencies F_1 and F_3 are synchronized and frequencies F_2 and F_4 likewise. The frequency and phase of the currents thus obtained are equalized by means of a special electric device which acts upon the phase and frequency of the slave transmissions.

Given these conditions, let M be the position, located at the unknown distances D_A and D_B from the transmitters, which requires to be fixed. A beat frequency is obtained between F_1 and F_3, as well as between F_2 and F_4, at M. The currents thus obtained are on an identical frequency, but show a phase difference of ψ. It may easily be shown that ψ is expressed by :

$$\psi = \frac{4 \pi F}{c} [D_A - D_B - d_A + d_B]$$

(1) The designers of Rana equipment have systematically investigated the possibilities afforded by phase measurement. Only such as the system applies to hydrography has the equipment been discussed herein, and the particular solution retained may of course not necessarily be the one best suited to other conditions.

c being the velocity of propagation and F being equivalent to :

$$F = \frac{1}{2}(F_1 + F_2) = \frac{1}{2}(F_3 + F_4)$$

The measurement of ψ, d_A and d_B being known, enables the determination of $D_A - D_B = 2a$, i.e. the geodetic hyperbola whose foci are located at A and B and which is a locus of the position of point M.

It will be noted that phase ψ varies by 2π when $D_A - D_B$ varies by half a wavelength $\frac{\lambda}{2} = \frac{c}{2F}$; the zero-phase hyperbolas intersect line AB at points $\frac{\lambda}{4}$ apart.

The system's only beats are those occurring between frequencies F_1 and F_3 on the one hand, and between F_2 and F_4 on the other, whence are derived the f-frequency currents; this may theoretically be any frequency, and is selected at the very-low level (less than 50 c/s), which facilitates the design of the phase-measuring device. There is no objection, moreover, to the selection of F_1 and F_2, and hence F_3 and F_4, on neighbouring frequencies. Finally all four frequencies are included in a narrow range and follow the same propagation laws. The four frequencies of each of the other two pairs are likewise included within this same bandwidth without the slightest difficulty.

The frequencies used are in the neighbourhood of 1623 kc/s and correspond to wavelengths of the order of 180 metres; the zero-phase hyperbolas are 45 metres apart on the baseline. The pattern is hence an extremely fine one, and the distance between the free and slave transmitters can be narrowed down to 10 km and even less. As will be described later, this is an advantage when plotting the hyperbolas on the survey sheets.

As the zero-phase hyperbolas are so closely spaced, some difficulty would be experienced in ascertaining which hyperbolas are located on either side of one's position, since measurement supplies the phase to within only $2k\pi$. In order to resolve this ambiguity, each pair transmits a third frequency F'_2 at the free transmitter and F'_4 at the slave transmitter, such that :

$$F_1 - F'_2 = F_3 - F'_4 = 2F' = 2\frac{F}{10}$$

By causing a beat frequency between F_1 and F_3 and F'_2 and F'_4, at M, a « coarse » pattern is obtained in which the zero-phase hyperbolas coincide with those of the fine pattern but in which only every tenth hyperbola is retained. A fix may thus be obtained without ambiguity within the coarse pattern, and thereupon also within the fine pattern.

It will be noted that the new F'_2 and F'_4 frequencies are not far removed from the initial frequencies. The space ultimately taken up by all the transmissions (three pairs each transmitting a fine and coarse pattern) is small. In the installation discussed herein, it was 7 Kc/s, hence less than that of a broadcasting station.

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Regardless of the equipment used in the phase method, the convenient application of results requires that projections plotted with the hyperbolic patterns be available. These are normally constructed by interpolating between the hyperbolas.

The velocity of propagation of radio waves must first be determined, as this velocity is involved in the formula giving the distance-differences in terms of phase-differences. The presently accepted value *in vacuo* is (1) :

$$c_0 = 299792 \pm 2 \text{ km/s}$$

This value is used as a basis for computing the velocities of propagation under particular operational conditions, due account being taken of the dielectric constant of the atmosphere, ground effect, and propagation paths. An indispensable requirement is allowance for the fact that propagation between the slave transmitters and antenna usually occurs over land and not over the sea.

Under these circumstances, the formula supplying the phase difference must be changed, and becomes :

$$\psi = \frac{4\pi F}{c}(D_A - D_B) - \frac{4\pi F}{c'}(d_A - d_B)$$

in which c and c' are respectively the velocities of propagation over water and over land of the F-frequency transmission.

After the velocities have been selected, the hyperbolas are defined by their parameter $2a = D_A - D_B = \frac{c\,\psi}{4\pi F} + \frac{c}{c'}(d_A - d_B)$.

The general procedure is to plot the zero-phase hyperbolas, i.e. those in which $\psi = 2\pi n$ (n being an integer).

In theory the curves representing the geodetic hyperbolas on the projection are complex curves. But as regards hydrographic surveying, which never extends beyond 150 to 200 km offshore, a conformal projection may invariably be selected such that the linear alteration is slight in the area to be surveyed, with the result that it may be considered to be constant over fairly extensive zones. It will then be sufficient to reduce the velocities c and c' used in the previous formulas, to the projection, and the problem will thereupon consist in obtaining a plot of plane hyperbolas.

This problem may be dealt with graphically by the method of circles centred on the transmitters. But in view of the crowding involved by this procedure, French hydrographers prefer the point-by-point method of computation. If the hyperbola is referred to its axes, we know that we can write:

$$x = a\,ch\,\varphi \qquad y = b\,sh\,\varphi$$

By assigning various values to φ, we can determine as many points of the curve as we like with reference to its axes. By drawing the x y grid on the survey projection as an overlay, the point-by-point transference of the hyperbola can then be accomplished.

The number of points requiring computation increases with the amount of curvature of the hyperbola, and the intervals of the variable φ must be selected accordingly. In the case of Rana, owing to the fact that short baselines are used, the hyperbola closely approximates its asymptotes, and three points on the projection usually suffice for plotting the hyperbolic arc.

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(1) Value adopted by The International Radio Scientific Union, Sydney, 1952.

Another method for plotting the hyperbolas consists in first drawing asymptotes defined by the angle they form with reference to baseline AB ($\cos \theta = \frac{2a}{AB}$), and then in calculating the distance between the curve and the asymptote by the following approximate formula, which is valid under normal conditions of application :

$$d = \frac{AB^2 \sin 2\theta}{16 D}$$

(D being the distance of the point to the centre of the hyperbola).

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After the patterns have been plotted on the projection, each pattern must be calibrated. This is an indispensable operation, as the choice of the velocities of propagation, which affects the computation of the patterns, is invariably unreliable, and as local unforeseen conditions may give rise to permanent disturbances. Such disturbances are of course those solely due to propagation, since those arising from the breakdown of a transmitter or a momentary change in propagation are automatically revealed by a monitor receiver similar to the shipborne receiver, but set up at a fixed position and consequently supplying constant indications.

The French method of calibration consists in determining the difference δ, expressed in terms of phase, between the geodetic position and the hyperbolic locus of position.

If, as is the usual practice, the zero-phase hyperbolas are numbered beginning with the zero-phase hyperbola passing through the slave antenna, it will readily be seen that this difference is obtained by an expression in the form

$$\delta = \alpha n + \beta$$

in which n is the (fractional) number of the hyperbola and α and β are two constants. Constant α is solely dependent on the velocity of propagation value adopted over water, and β on such value adopted over land. By taking a maximum number of measurements over the entire pattern, α and β may be determined.

It has been ascertained that it does not suffice for the purposes of Rana to determine the geodetic position of the mobile by means of observations taken by hydrographic sextant within sight of land, since the amount of accuracy thus obtained — although adequate for routine hydrographic work — does not allow the maximum benefit to be derived from Rana, which is capable of greater precision. Hence the practice has developed of determining the geodetic positions by means of land-based theodolites fixing the position of the mobile operating about ten miles offshore. In general the value of α has been found to be zero, thus indicating that the adopted value for the velocity of propagation over water is correct.

As regards β, however, non-zero values are almost invariably found, which are constant for a particular pair but which vary as between one pair and another.

It is of course true that on the basis of the value of β, the velocity of propagation over land could be determined and the hyperbolic pattern recomputed, but it is simpler to correct all the pattern readings for the β constant than to start the tedious work of computing and plotting the hyperbolas all over again.

Calibration also shows that anomalous zones of propagation occasionally occur, revealed by a scattering of the values found for α and β. It may here be pointed out that in the vicinity of the baseline these are detected often, as the paths of the waves are then parallel to the shore. The obvious conclusion is that the convenient and rapid methods of calibration which consist in the intersection of the baseline may under certain conditions be of mediocre value.

In the last analysis, calibration indicates the corrections that must be made to the readings in each pattern. After all the corrections have been made, it will be found that, except of course as regards the anomalous zones, the triangles of error do not have a systematic appearance, so that their dimensions give an exact indication of the accuracy obtained.

No detailed description will be given of the equipment, which, although developed up to a point, is still in the temporary stage. The free transmitter groups are of extremely small dimensions; the larger slave transmitters can be broken down into units of the same size as the free transmitter. Powering requires the use of two electric generators per station, to ensure continuous operation; these are moreover used for ordinary living purposes at each station (lighting, cooking, heating or refrigeration). The antennas are of the ordinary whip-type, ten metres high, guyed, and can be set up easily.

A brief summary of the results achieved with the experimental chain during the 1954 trials in the Seine estuary, and during operations off the coast of Morocco in 1954 and 1955, is given below :

With an antenna output power of 1 watt, the range is 100 miles during the daytime and 80 miles at night. No night effect was noted within these range limits.

Absolute accuracy scarcely appears to depend on distances within the above-mentioned ranges, and is less than 10 metres.

Relative accuracy is far higher, amounting to a fraction of a metre.

The independence of the three position lines, the relatively convenient siting, and the short baseline-length make this equipment (which is still in the refined prototype stage) well-suited to offshore hydrographic surveying.