GENERAL COMMENTS REGARDING USE OF RADIOLOCATION SYSTEMS AND ULTRASONIC SOUNDING IN HYDROGRAPHY

by Ingénieur Hydrographe Principal LUNEL

Statement prepared for the Meeting on Radiolocation held from 24th to 27th October, 1956, in Hamburg (translated from the French text).

One of the primary aims of hydrography is the establishment of submarine topography in order to ensure the safety of navigation by locating shallows and delimiting channels, as well as to supply aids for making landfall by soundings, and for trawling. Following the increase in shipping, draught of ships and extent and number of zones frequented, hydrographers since the end of the First World War have adopted the principle of regular surveys which include the following operations:

(a) Systematic soundings at scales varying from 1 :20,000 for depths of less than 30 metres to 1 :50,000 for depths down to 100 metres. Soundings down to 1,500 metres or more are plotted at scales of 1 :100,000 or above.

(b) Close soundings for all areas in which the possible existence of a shoal has been indicated by previous investigation and as a result of all additional information.

(c) Sweeping of channels with heavy traffic or points of compulsory passage in which the crests of rocks may have passed unnoticed or been covered by wrecks or other obstructions. This operation does not call for very accurate position-fixing as the swept strips overlap amply. This plan could have been put into effect long ago in shallow water up to the limit of sight of land. Its extension implied the putting into operation of continuous and automatic sounding devices and of accurate position-fixing methods. The introduction of echo sounding as of the end of the First World War supplied the solution to the first problem.

I. — ECHO SOUNDING

The first echo sounding devices used a source of acoustic energy which had good propagation qualities but was impossible to direct. Therefore use was made of ultrasonic signals transmitted in narrow beams and produced either by piezo-electric or magnetostrictive means.

The first instruments date back to the 1923-1930 period, although Professor Langevin had produced a prototype in 1920. They reached their final form after the Second World War and, for the most part, are of the magnetostrictive type. This type calls for considerable power at the time of transmission, and often involves the installation of two separate bases for transmission and reception, but it is justified by the fact that it is easier to construct an oscillator consisting of a cylindrical pile of nickel rings than of a quartz mozaic. Certain models incidentally (Edo -

U.S.A., Scam - France, Marconi - G.B.) operate from a single base. As the magnetostrictive action is reversible, the nickel in fact retains a residual magnetism supplied by each cycle as long as the exciter current always flows in the same direction. The Villari effect upon reception is, under these conditions, sufficiently strong.

The frequencies used vary according to the range of the sounder:

— 30 to 80 kc/s for shallow-depth sounders, the accuracy improving in proportion with the decrease in the wavelength, subject to the dimensions of the oscillator;

— 10 to 30 kc/s for medium-depth and deep-sea sounders, the reduction of propagation varying in inverse ratio to the frequency. Ranges of 10,000 metres are normally obtainable with equipment of the Edo Model and NBC - U.S.A. type; ranges of 6,000 metres with the Hughes 26 H (G.B.) type.

Except for very special requirements, the power transmitted can, without inconvenience, and even in shallow water, be contained in a cone of fairly large aperture. Consequently no problem is raised regarding the form of the base and signal projector: for a 15 × 15 cm. base and a 30 kc/s frequency, the transmission-reception pattern is such that half the received power is contained in a cone with 9° aperture.

The accuracy (10 cm.) required for shallow-water hydrography is generally obtained. A greater accuracy would be fallacious in view of the fact that the position of the sounding craft in relation to the plane of reference is less clearly defined; it moreover would be improved with difficulty: the reading varies slightly according to the sensitivity of the receiver, as the transmitted pulses are not strictly rectangular. At other depths, the error can be reckoned to be 1 % of the sounding figure, under optimum conditions.

The starting up and operation of present-day instruments are easy (i.e. small space requirements; feeding by storage batteries possible because of low nominal power used; excellent protection; recording presented on unalterable metallized paper). Finally, the instruments still function correctly in fairly rough seas.

II. — SOUND RANGING

At the present time, the possibilities offered by ultrasonic sounders unquestionably meet all the needs of hydrography. We shall now show how the problem of accurate position-fixing out of sight of land was solved.

The first devices constructed at the end of the First World War used the horizontal propagation of sound waves. This method, which was perfected in France by Ingénieur Hydrographe Marti, is called sound ranging. It enables fixing the distance, or distance-differences, of a sounding craft from two or three submarine microphones of known position by determining the travel time, or the travel-time differences, of sound waves transmitted from the sounding craft and received by the microphones. The position lines are accordingly either circles or hyperbolae of which the centres of foci are the microphone sites.

Two difficulties, however, arose:

— the existence of a sound channel caused by the presence of steep temperature gradients or inversions precludes certain sound paths, thus producing fading in the reception;

— the speed of propagation of the sound waves is dependent on the characteristics of sea-water (i.e. temperature and salinity); consequently, a certain element of doubt remains regarding the velocity to be adopted in areas of steep gradient in order to reduce the measured travel time to distance.

III. — RADIO METHODS

These difficulties led research workers to turn towards methods based on the propagation of radio waves and which had been considerably developed during the Second World War. Is should be noted here however that although the improvements made in radio techniques have solved the problems of the transformation of radio power inside the instrument circuits, the same ambiguities and anomalies are met with in the propagation of radio waves and sound waves.

The instruments used fall into two different categories:

The first is of the pulse type. These very short pulses are transmitted by the mobile, received by fixed responder beacons set up on land, and returned on a different frequency towards the mobile where the time taken for the round trip, minus the time delays at the responders, is measured and then transformed into distance. The position lines are concentric circles.

The second is of the phase-comparison type in which the phase difference between two synchronized waves radiated by two transmitters, A and B, is measured at C, from which the difference in the distances to the two transmitters is derived to the nearest multiple of the comparison wavelength. The position or equiphase lines are geodetic hyperbolae with the transmitters as foci. By various modifications of the block diagram, it is moreover possible to reduce the system to position lines formed by concentric circles.

IV. — CHARACTERISTICS OF RADIO POSITION-FIXING SYSTEMS FOR HYDROGRAPHY

From the methods described above, several types of instruments have been constructed for various requirements. The most suitable have been applied to hydrography; some of them were in fact designed for this purpose in the first place. Before considering them, it is necessary to set out the conditions which they have to satisfy. These can be listed as follows:

— Repeatability and therefore accuracy consistent with the scale of the survey, i.e. with the average depth of the areas sounded;

— Calibration and consistency, by means of three position lines;

— A general range of 100 miles — more in some particular cases;

— Real mobility of the chain and flexibility in choice of land station sites;

— Intensive use during successive periods of limited duration;

— Presence of a system of identification;

— Easy plotting of position lines.

(a) *Repeatability and accuracy after calibration.*

Repeatability R of a chain is an essential characteristic. It must permit the consistent and homogeneous plotting of the tracks followed by the sounding vessel to within the nearest millimetre, at the survey scale, representing the following distances:

— 10 metres for a survey at 1 :20,000 in 65 % of the cases;
— 25 metres for a survey at 1 :50,000 in 65 % of the cases;
— 50 metres for a survey at 1 :100,000 in 65 % of the cases.

This represents overall repeatability. Lateral repeatability f_1 and f_2 on each position line should be better:

$$R = \frac{1}{\sin \beta} \sqrt{f_1^2 + f_2^2} \qquad (1)$$

(β being the angle of intersection of these two lines.)

If β is taken as equal to 45° and the lateral repeatability f_1 and f_2 are assumed to be equal, it follows that $f_1 = f_2 = \frac{R}{2}$.

The *accuracy* of a chain is dependent on its repeatability and is of the same order. In fact, before any survey, the calibration of the chain is undertaken on each pattern by the comparison of visual and radio fixes taken simultaneously. The visual fix by sextant cannot be sufficiently accurate; therefore it is necessary to operate by sights on the vessel with theodolites at a ground station. This check can be carried out up to the limit of visibility and supplies local corrections in the area.

Beyond that point, it is imperative to ensure that the established corrections are still valid, whether they have been recognized as applicable to a wide area or as dependent on the position line number, or whether it has been believed possible to extrapolate the lines of equal correction. It is for this purpose that a hydrographic system should supply *three* position lines, the construction of which, after correction of the readings, makes it possible to ensure that they are highly consistent, i.e. that they *actually intersect at one and the same point* to within the nearest margin of error allowed; under these circumstances, it is said that the « cocked hats » encountered have, when drawn up, a plot radius of less than 1 millimetre. If this is not the case, a study of the « cocked hats » in areas in which they appear systematically makes it possible, in many cases, to determine the pattern which offers a propagation anomaly, whence the particular advantage of having three position lines available.

(b) *Range.*

Ranges of from 80 to 100 miles have, up to the present time, generally been sufficient. Surveys beyond sight of land have, however, been undertaken, but at scales of less than 1 :200,000 at which repeatability requirements are less important.

(c) *Mobility - Siting.*

Mobility is a primary characteristic of survey systems, and two cases may arise, depending on whether or not the coastal area is adequately serviced by roads. In the first case, the ground equipment can be delivered by truck, whereas in the second case, in undeveloped or relatively deserted areas, it will be delivered to the site by sea under conditions often fraught with difficulty, thus leaving no great latitude in the siting of the stations. *Flexibility in the choice of sites is therefore of considerable importance.*

In both cases the equipment should consist of lightweight and space-saving units, powered by transportable generating sets of 1 to 5 Kw, sheltered under tents or huts, equipped with sectional antennae, tropicalized and protected with care.

The need for such action is further stressed if it is planned to install a mobile station (a receiver, indicator or relay station) on light craft (a launch or motor-boat), whereas relatively heavy equipment can be installed on the main ship.

In order to reduce the number of stations and facilitate logistical support of the ground installations, most hydrographic systems so far developed only supply two position lines. However, whereas this is an acceptable restriction in the case of surveys along coasts unserviced by roads, it is far less justified in the opposite case. In order that the required 80- to 100-mile ranges may be secured in spite of reduced antenna power, the stations should be sited at the sea-edge, with the signal-paths between stations in so far as possible over water.

(d) *Utilization.*

The final test in the definition of a survey system is the intensive utilization of the chain and of the results. Efficiency will be high only if it is possible to compensate for the time lost during installation by continuous use during twenty-four hours a day and six days a week for sounding operations, until completion of the project; the delays due to installation and dismantling are thus of the same order as the duration of soundings. Any interruption in chain operation, or any additional loss of time due to readjustment following repairs would considerably reduce performance; the question of efficiency also requires the *presence of an identification system* enabling operation out of sight of land during long periods, even in the event of short interruptions.

In many instances a hydrographic surveying expedition consists of a single large vessel responsible for the major soundings; and the use of a saturable system, i.e. with one transmitter on the mobile, does not cause any inconvenience.

Pattern operation must be controlled at a ground station, called the *monitor station*, where a receiver is installed and theoretically constant readings are recorded. A record is taken of readings on board the mobile, to facilitate analysis. Finally, rapid plotting of the tracks followed must be considered. This requires prior construction on the plotting sheets of round values of the equiphase or equal-distance lines, allowing interpolations between.

If the theoretical assumption is that the fix should be obtained to within one millimetre at survey-scale, it is clear that the fix should be plotted from computed points to within two tenths of a millimetre, without overstepping the limitations of the particular survey operation. Two cases are especially favourable:

— the case of hyperbolic lines of equal phase almost coinciding with their asymptotes;

— the case of circles of equal distance with their centre on the plotting sheet, and which may be plotted graphically with probably adequate accuracy.

(e) *Accuracy and frequency.*

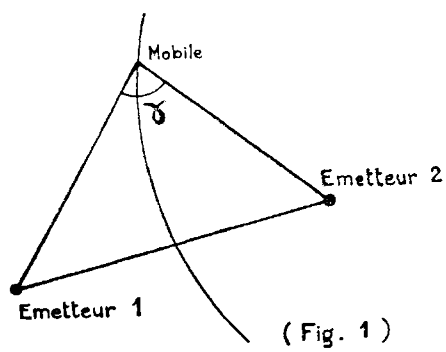
The *internal* accuracy $\Delta\varphi_0$ of a phase-comparison system is limited by stability of synchronization and by the accuracy of measurement of the phase differences. The difference corresponding to the position line is (see Fig. 1):

$$\frac{1}{\sin\frac{\gamma}{2}} \; \frac{\Delta\varphi}{360} \; \frac{\lambda_c}{i} \qquad \text{for a hyperbolic system,}$$

λ_c being the comparison wavelength, γ the angle subtended by the transmitters, and i a factor equal to 2, 4..., according to the system.

$$\frac{\Delta\varphi}{360} \; \frac{\lambda_c}{i}$$

for a circular system, which is not affected by lane expansion.



(Fig. 1)

$\Delta\varphi_0$ is invariably of the order of 5° or more, and all things being equal, internal accuracy increases as the wavelength decreases, and with the length of the baseline.

Accurate measurements are only possible with the direct wave, and the type of propagation of the transmitted waves determines the *external* accuracy. The decrease in range of the direct wave, and the variations in phase and amplitude of the indirect wave preclude the use of transmission wavelengths under 150 metres, with the result that only long and medium waves are used. The survey area in general covers a 100- kilometre extent of coast per season, and baseline lengths of 40 to 50 kilometres need rarely be exceeded.

In the case of pulse systems with a very high carrier frequency, internal accuracy is dependent on the following factors:

— variations in delay within the circuits;

— incorrect matching of pulses;

— variations in delay following variations in signal strength.

The overall accuracy may here be evaluated at 15 carrier-wave lengths.

V. — ADAPTATION OF RADIO SYSTEMS TO HYDROGRAPHY

A brief analysis has been given of the requirements of a radio position-fixing chain to be used for hydrographic purposes. Actually attempts were first made to adapt existing systems designed for other purposes, such as:

— DECCA (navigation);

— SHORAN (tracking of aircraft);

— RAYDIST (oil prospecting).

No account will be given of the basic principles of these aids; discussion will be limited to improvements that have now been added.

(a) *DECCA system.*

The DECCA system is a fairly complex one technically, as it requires frequency division and multiplication. Its technical development has been remarkable; and since 1947 has enabled numerous surveys to be carried out under normal operating conditions in several countries, including Sweden, Greenland, Great Britain and France, through the use of two-dimensional mobile chains.

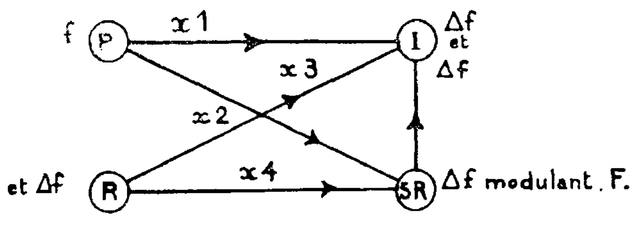
A survey type of receiver equipped with a precise reference device and with linear control of the phasemeters, enabling readings to be obtained to within one-hundredth of a lane, has been developed, but does not include an identification system.

Two designs have been suggested in order to counteract a certain heaviness in the ground installations, the limited choice in station sites, and the difficulty in the plotting of hyperbolae, which requires lengthy precomputation. The first design is the *Short-Base DECCA* system, in which each pattern is from 50 to 100 km. apart, the baseline length in each case being 10 km. The system is only suitable, however, for surveys up to a scale of 1:100,000: although the arrangement of and distance between the patterns enables good position-line intersections to be obtained over a wide area, the lane-expansion factor, which affects lanes that are 500 metres wide already at the baseline, rapidly increases away from the transmitters. It will nevertheless be noted that as the baseline length is reduced to 10 kilometres, the effect of the indirect wave over this path is eliminated.

The second is *Two-Range DECCA*, in which the main transmitter (master) is shipborne, together with the receivers. This saturable system supplies two position-line patterns consisting of circles centred on the two shore-based slave transmitters. The increased accuracy (which is constant during daylight over a wide area), the fact that the ground stations are reduced to two, the independence of the two position lines whose paths are entirely located over water, make this method an extremely valuable one for hydrographic purposes in the case of soundings on the scale of 1:50,000 or under. However, use of the system appears to be limited to daylight, owing to the long signal paths, which are appreciably affected by the reflected wave even at medium ranges.

(b) *RAYDIST.*

The RAYDIST system has been in use since 1946 for hydrographic surveying purposes. It is of the phase-comparison type, operates on 200- metre wavelengths and makes simultaneous use of frequency multipliers (factor 2), beat-frequencies (BF) (200-400 cps), and modulation of carriers by means of such beats.



(Fig. 2)

The basic skeleton diagram (see Fig. 2) consists of:

— a master transmitter P ($f = \frac{v}{\lambda}$);

— a reference transmitter R ($f + \Delta f$);

— a relay station SR (F modulated by Δf);

— an indicator station I (which compares the phase of $2 \Delta f$ cps beats).

Various types of position lines are obtained according to the arrangement of the above units: the phase difference read off at the indicator station is given by the general relationship :

$$\Delta \varphi = \frac{2\pi}{\lambda} (x_1 - x_2 - x_3) + \text{constant} \qquad \text{(II)}$$

(which to within a negligible shift in phase is equivalent to $\frac{2\pi}{\lambda} \frac{\Delta f}{f} (x_5 - x_2)$.

The constant in particular includes the phase difference as between the receiver and transmitter at the relay station: this usually fixed shift in phase may vary after repairs, replacement of valves or other units. The chain thereupon must be recalibrated by comparison of a visual fix and a RAYDIST position, which may entail delay.

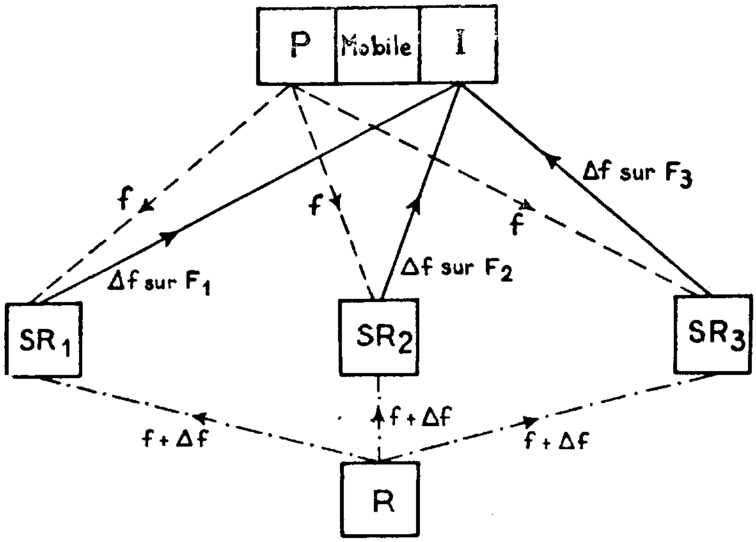
Type E was used for shallow-water surveying by 1946, and presented the following characteristics:

— a range of 20 miles, with higher than 10- metre accuracy;

— light weight of the two transmitting stations and three relay stations, powered by 6 V/200 A storage batteries (Antenna output: 10 watts);

— the system is of the saturation type, since the master transmitter is placed on the mobile station;

— the receiving-indicating station, which records the signals, is powered at 110 volts. The low-frequency beats of the high-frequency waves radiated by the two transmitters are compared at the station, detected by each of the relay stations SR1, SR2, SR3, and retransmitted on carrier frequencies F_1, F_2, F_3 (see Fig. 3). The position lines are hyperbolae with their foci at the relay stations.



(Fig. 3)

The Mozambique Hydrographic Survey has been using equipment of this type since 1952. In spite of a power increase to 100 watts in order that 100- mile ranges might be obtained, and the resulting increased weight and space required, the chain is still transportable even though it must be landed on an exposed coast. Accuracy within the limits of range indicated is better than 80 metres.

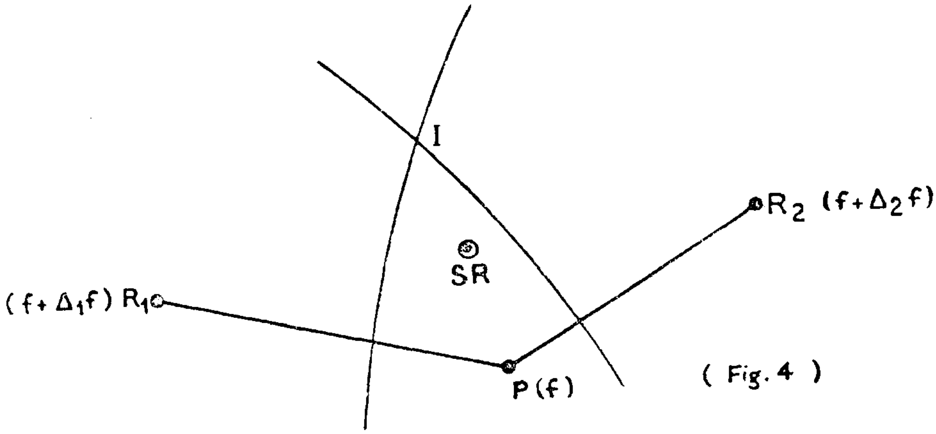
In 1953, the Portuguese Guinea Survey initiated operations with a transportable non-saturable *Type N* system, in which the master transmitter P is shore-based and the indicator on the mobile. Two reference transmitters R_1 and R_2, and a relay station SR (see Fig. 4) complete the installation, which supplies two position lines. Referring back to formula (II) and Fig. 2 with x_2 constant, we get:

$$\Delta \varphi = \frac{2\pi}{\lambda} (x_1 - x_3) + \text{constant} \qquad \text{(III)}$$

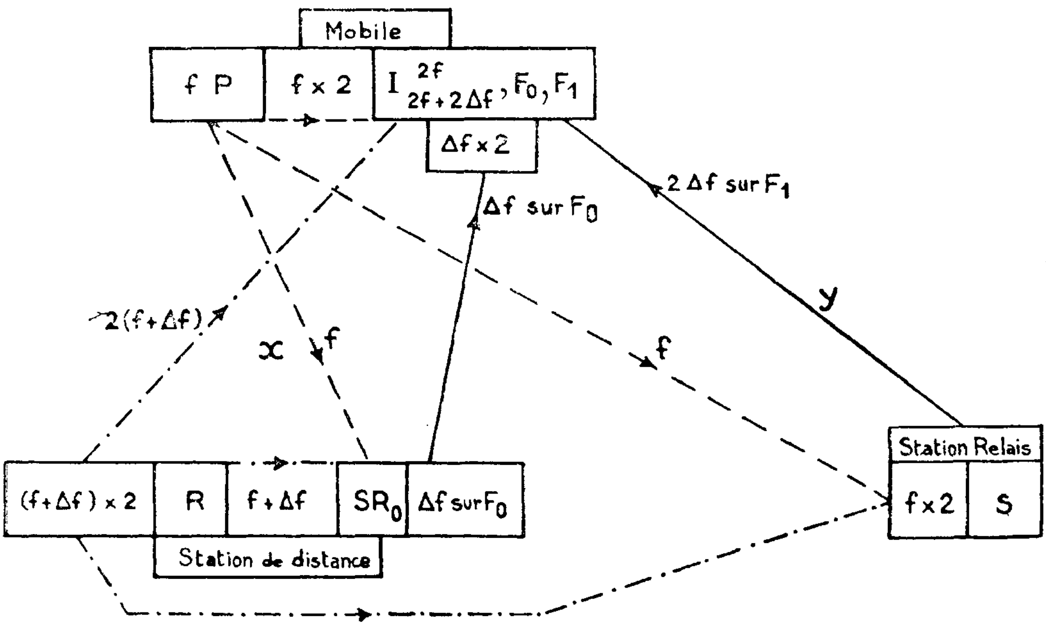
The lines of equal phase are hyperbolae with their foci at P R_1 and P R_2.

This arrangement is not equipped with an identification system. The chain covers 100 km. of coastline at a maximum range of 100 miles. Owing to the length of the signal paths P — SR, R_1 — SR, and R_2 — SR, which are of the order of 50 km., and owing moreover to the shift in phase due to retransmission from the relay station (amounting to a maximum of 10 hundredths of a lane), the maximum survey-scale appears to be 1 :75,000. It should finally be noted that a fairly large amount of calculation is required for plotting the hyperbolae.

Since 1955, *Type ER* or « two-range » systems have been used successfully in Brazil, Argentina and Venezuela. This type has the same range characteristics at the same power level as the Type N and E systems, but can be installed with greater ease, as there is only *one ground station per position line,* and it is as easily transportable, light in weight, and takes up as little space as the previously described systems. The position lines reduce themselves to circles centred on the shore transmitters (or to a circular and hyperbolic system).


I
SR
R₂ (f+Δ₂f)
(f+Δ₁f) R₁
P (f)

(Fig. 4)


Mobile
f P
f x 2
I 2f / 2f+2Δf , F₀, F₁
Δf x 2
2 Δf sur F₁
Δf sur F₀
y
2(f+Δf)
x
f
f
Station Relais
f x 2
S
(f+Δf) x 2
R
f+Δf
SR₀
Δf sur F₀
Station de distance
2 (f+Δf)

(Fig. 5)

The equipment combines a distance measurement with a distance-difference measurement, and consists of (see Fig. 5):

— a master transmitter P and an indicator station I on the mobile;
— a range station (reference transmitter R and relay station SR);
— a relay station SR_1.

The system is of the saturable type.

f = 1.5 Mc/s being the frequency of the master transmitter, the indicating station measures the following phase differences:

$$\varphi_1 = -\frac{2\pi x}{\lambda/2} + C_1 \qquad \text{(IV)}$$

between the 2 Δ f beats of transmitters P and R and the 2 Δ f beats retransmitted on F_0 by SR_0 (the equiphase lines are circles centred on the range station. One lane is equivalent to 100 m.).

$$\varphi_2 = -\frac{2\pi}{\lambda/2}(x - y) + C_2 \qquad \text{(V)}$$

between the 2 Δ f beats transmitted on F_0 and F_1 by SR_0 and SR_1 (the equiphase lines are hyperbolae with their foci at the two ground stations. One lane is equivalent to 50 m. on the baseline).

It should be noted that an additional relay station SR_2 would enable a third position line to be obtained.

This Type ER system is therefore *eminently adapted to hydrographic needs.* The author unfortunately possesses no indications as to final accuracy and its possibilities for use at night.

VI. — SYSTEMS DESIGNED FOR PURELY HYDROGRAPHIC PURPOSES

In addition to the systems described above, there exist others primarily designed for hydrographic purposes, such as:

— EPI (Electronic Position Indicator);
— LORAC (LOng RAnge ACcuracy);
— RANA.

(a) *Electronic Position Ranging.*

The EPI system is a pulse system which was used in 1947 for surveying in the Gulf of Mexico, and later in Alaska by the Coast and Geodetic Survey. It is based on a principle quite different to that of Shoran, in order that it may be used at long ranges (250 miles) on a small plotting scale (1 :100,000 or 1 :200,000).

The answering pulse is no longer *triggered* by the mobile transmitter pulse as in Shoran, but is *synchronized* by it. The carrier frequency passes from 250 Mc/s to 1.8 Mc/s. The antennae are 30 feet high and overall bulk is high although the equipment is reduced to two ground stations. The position lines are circles. Accuracy is of the order of 45 metres in 65 % of cases of range measurements.

(b) *LORAC.*

Lorac is a transportable, hyperbolic system, which compares the phases of:
— a low-frequency reference signal modulating a carrier wave radiated from one of the stations.

— a position signal obtained by detecting the beat between the two adjacent frequencies radiated by the two stations of a pattern.

The lanewidth on the baseline is of the order of 100 metres. Three shore stations supply two position lines. No additional details will be given, since this system closely resembles a previously described type.

(c) *RANA.*

The RANA system is a particular instance of the RANA methods involving a general investigation of the possibilities offered by the simultaneous propagation of pure continuous waves for position-fixing purposes. Ordered by the French Navy Hydrographic Office, it has been used since 1954 off the coasts of Morocco, and consists of three pairs of *independent* transmitters supplying *three* hyperbolic position lines. It is of the non-saturable type.

For each pair, each station transmits on *three* frequencies, which bear certain relationships to each other, and are located in the 1600-1800 Kc/s band. The mobile receiver compares two sets of two low- or medium-frequency beats and displays their phase difference.

Two hyperbolic equiphase systems, with their foci at each transmitter, are thus defined. For one of these systems the lanewidth at the baseline is

$$\frac{\lambda_m}{4} \# 45 \text{ metres.}$$

The other system, in which the lanes are 20 times as wide, serves as a means of identification. A pair is precisely locked in phase through control of a « slave » transmitter by a servo-receiver in which the measured phase differences must remain constant.

The transmitters may be sited only 10 km. apart, and the indirect wave does not affect the signal path. Sensitivity is nevertheless excellent, since the smaller lanewidth amounts to a bare 45 metres. The extent of coastline covered by a chain amounts to 80-100 km., and range to 80-100 miles for an antenna output power of 1 watt. After calibration, consistency to the limit of range, controlled by the radius of the « cocked hats », is better than 30 metres. Accuracy may be evaluated as of the same order. No night effect has been discovered, and surveys are conducted intensively on a continuous sounding basis. Any variation in the characteristics of the transmitter circuits likely to cause shifts in phase is automatically corrected by the locking device.

The equipment is transportable, but certain details of design should be revised so that it can be used in areas not serviced by roads (the power units, for instance, are too heavy). The large number of shore stations is counterbalanced to a degree by flexibility in the choice of station sites and control by three position lines.

As the system is used beginning twenty kilometres off shore, the hyperbolae are sufficiently close to their asymptotes to warrant the use of rapid computation methods for the patterns, and without straining the facilities afforded the survey.

VII. — CONCLUSION

The above enumeration of radio systems used in hydrography is far from complete, in that it does not include all the methods capable of being used for survey purposes. In view of the very general scope of the present paper, it was decided that it would be more important to analyze the peculiarities of hydrographic problems and the need for constant adaptation and development before they can be completely solved. Such considerations have involved the discussion at greater length of a certain type of instrument.

To conclude, it appears that the efforts of researchers and technicians might be directed as follows:

— maximum lightening of installations through use of new materials (transistors, etc.);

— reliability and simplicity of equipment through use of parts of very high quality;

— invariability of time constants or synchronization;

— better knowledge of modes of wave propagation.

On the basis of advances made during the past ten years, it appears that such efforts should be successful within a fairly short period, and that this delay will be appreciably shortened by the international cooperation promoted at the present meeting.

The possibilities offered to hydrographers by ultrasonic sounding may then be used to the utmost for the precise and complete determination of underwater topography.