RADIO AIDS TO HYDROGRAPHIC SURVEYING AT LIVERPOOL (*)

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Liverpool Bay is an area of notoriously bad visibility. Taking an average over a twelve year period, there are 140 days per year when visibility is two miles or less for all or part of the day, making it impossible to fix on shore marks. In addition, there are about 100 days a year when the state of the sea makes accurate surveying impracticable. As these two sets of conditions seldom overlap, it means that there are only about 120 potential surveying days per year and, unless work is done at weekends with the resulting overtime costs involved, this total is further reduced to about 90 days when routine surveys can be carried out.

The programme of routine work in Liverpool Bay consists of five large scale channel surveys once a month, each being about a day's work, plus an annual smaller scale survey of the remainder of the Bay which occupies about 20 working days. In addition, there are a number of annual large scale surveys taking one or two days each, and it will be seen that the total is approximately the 90 days available.

However, this takes no account of days lost due to surveying craft being under refit or required for non-surveying operations, nor does it take account of the fact that some surveys are also dependent on the state of the tide, nor of the fact that the periods of gales and/or poor visibility may make it impracticable to do any surveying for six to eight weeks at a stretch which throws out of balance the desired monthly surveying programme.

Apart from taking soundings, a considerable amount of other surveying activity is affected by poor visibility. The main item is wreck sweeping and channel sweeping for obstructions. In this work, the vessel concerned frequently made a passage out to the area concerned in the hope of improving visibility and, in fact, was unable to do anything all day, with the resulting waste of time and money.

(*) Published with the authorisation of Captain W. R. Colbeck, R.N.R., F.R.I.C.S., Marine Surveyor and Water Bailiff of the Port of Liverpool.

1. — First developments of radio aids

Up to the time of the last war, these conditions had to be accepted, but operational requirements during the war brought about considerable advances in the techniques of position finding by radio aids.

Two of the most remarkable developments were radar and the Decca Navigator, and surveyors were quick to appreciate the potential value of both.

With regard to the latter, a demonstration was arranged in October, 1945, on the initiative of the then Ministry of War Transport, by the Hydrographer of the Navy. A mobile Decca chain of low power was established in the Bristol Channel and a receiver fitted in H.M.S. *Franklin* (Commander E.G. Irving, O.B.E., R.N.). This demonstration was for the benefit of the marine officers of the principal U. K. ports and Trinity House and, on behalf of the Mersey Docks and Harbour Board, Captain H.V. Hart, O.B.E., R.D., R.N.R., at that time Marine Surveyor and Water Bailiff, attended.

He reported very favourably on what he had seen and stated that whilst he did not consider the system suitable, as yet, for the navigation of large vessels in the narrow buoyed channel of the approach to Liverpool, with its strong tidal streams, it was eminently suitable for surveying in coastal waters and Liverpool Bay and would be of great value to the Pilot vessels.

He recommended to the Board that the system should be adopted in Liverpool as soon as stations could be erected ashore.

The matter was discussed in detail with the Decca Company and a scheme outlined with a master station at Lymm, Cheshire (53°22′ N, 2°27′ W) and slave stations at Garstang, Lancashire (53°53′ N, 2°44′ W) and Mold, Flintshire (53°09′ N, 3°07′ W) which, it was claimed, would give a fix of accuracy ± 20 feet in the vicinity of the Bar Lightvessel and approximately ± 1 cable at 50 miles distant from Liverpool. However, it was pointed out by Decca that a guaranteed minimum of 30 ships fitted would be required.

At first this seemed no obstacle but, when enquiries were made among local shipping interests, very few were prepared to fit an aid which would only be of use from Liverpool to Holyhead, the Isle of Man or Barrow.

It was still thought possible to reach the minimum figure and sites were selected and equipment for a trial ordered. At this stage, the Ministry of Transport, who had overall control of the priorities of establishing Decca chains around the U.K., decided that after the completion of the English Chain (covering the English Channel and South East Coast) a Scottish Chain should follow before a Mersey Chain. Also the Decca Company indicated that a figure of 50 vessels fitted was desirable instead of 30 so that, for the time being, the project was shelved.

Eventually, a chain to cover a much larger area was installed. This was the North British Chain which became operational in June, 1951, with a master station in Wigtown and slave stations at Lurgan in Northern Ireland, Walkworth near Newcastle and Neston, Cheshire. This chain gave coverage to the whole of the Irish Sea and North West Approaches and the North East coastal waters.

2. — Trials of navigational Decca for surveying

Though it was obvious that this system would not give a very high order of accuracy in Liverpool Bay, it was decided to fit a receiver experimentally and to assess the accuracy which could be expected under different conditions. Accordingly, a standard Q.M.4. receiver was fitted in the survey tender *Aestus* in July, 1951, and a large number of shore fixes obtained with their correlative Decca readings. The results were somewhat disappointing. In November, 1951, a launch secured alongside a moored lightfloat for two hours and read off the decometers at five minute intervals. During this time there were fluctuations about the mean values as follows :

Red ± .03, i.e. ± 168 ft
Green ± .025, i.e. ± 90 ft
Purple ± .035, i.e. ± 44 ft

Thus the only reading approaching surveying accuracy on large scales was the Purple whose slave was at Neston, only about twenty miles away.

In December, a further experiment at another moored lightfloat gave worse results with errors of ± 850 ft, ± 460 ft and ± 80 ft respectively.

These results were forwarded to the Decca Company who explained that the system could not give better results than this under prevailing conditions. The main factor affecting the stability of readings at a point being the daylight conditions, i.e. in the latitude of Liverpool for the months of November, December and January there is no daylight as recognised by decometers, only light and twilight during which time, for the more distant slave stations, a proportion of the signal comes from the skywave which is received at a slightly different phase from the direct wave. It was pointed out by the Company that in the summer months the errors would be reduced to between a quarter and a third of the winter values. Subsequent checks in the summer of 1952 confirmed this and, after a large number of fixes on different days in different parts of the Bay, it was concluded that between April and October of each year the system could be relied upon to give errors not exceeding ± .020 on Red, ± .025 on Green and ± .015 on Purple, for 75 % of the time. In effect, this meant that a fix of the order of ± 120 ft might be expected and this was adequate for the survey of Liverpool Bay on a scale of 1/18 000 and for some channel sweeping operations with a rope sweep of 600 ft — 800 ft spread with a 50 % overlap.

Working sheets were, therefore, prepared with the Decca lattice superimposed. The best cut was obtained using the green and purple lanes though the width of a lane also had to be considered. This varies with the comparison frequency used for each pattern and the position of the receiver in the hyperbolic grid. The lane width values on the baselines for the three patterns of the North British chain were approximately Red 1 400 ft, Green 1 900 ft, and Purple 1 100 ft. However, in the area of Liverpool Bay, whilst the purple lane width remained at 1 100 ft as the baseline passed through the area, the Red became 5 000 ft and the Green 4 200 ft so that in all ways the use of the green and purple patterns gave the most accurate fix and these were used.

The system as a whole gave satisfactory service for surveying on the 1/18 000 scale. A note was kept of the variations at a point, during summer and winter conditions, until 1955 and the pattern became clear of a larger spread of values in winter than in summer although the very poor results of 1951 were not repeated subsequently. One suggested explanation of this has been that the level of sunspot activity varies from year to year and affects the relative amounts of "daylight", "light", and "twilight" as it affects radio waves in the Decca Navigator band. Another noticeable factor was the effect of electric storms. A thunderstorm in the vicinity of a receiver or between a receiver and a slave station caused considerable instability of the pattern. Also, snowstorms and severe rainsqualls between a ship and a transmitter made the system unreliable.

The purple lane in general gave very stable results and for 1/6 000 scale work some plotting sheets were made using this lane in conjunction with one pair of shore marks which subtended arcs cutting the purple lane at a good angle.

In May, 1957, the layout of the North British chain was modified to provide better coverage on the North East Coast. Unfortunately, this move reduced the accuracy of the system in Liverpool Bay. The actual movements involved the green and purple slaves. The original purple slave remained physically at the same site but its frequency was changed to make it the green slave. The original green slave was moved north to Stirling and its frequency changed to make it the purple slave. The effect in Liverpool of this was that the new green slave transmission, being at a lower frequency than when it was the purple slave, produced a pattern whose baseline width was approximately 1 800 feet as opposed to 1 100 feet previously. Although the cut produced by the new purple slave with the new green slave was improved, the move north increased the lane width considerably in the Liverpool area so that with the new arrangement the most accurate fix was obtained by the combination of the red pattern with the new green pattern. The accuracy claimed for a variation of $\pm$ .01 lane under summer daylight conditions was $\pm$ 60 ft. Some further research into the unexplained errors experienced with the equipment during summer daylight conditions had indicated that a part of the trouble could be due to drops of water on the receiving aerial carrying static charges and reducing the sensitivity of reception. To overcome this a new type of aerial was fitted with a fibre glass covering. Also, a more sensitive type of receiver, the survey type 375, was fitted at the end of 1957 and the combination of these two produced more encouraging results. It was considered that under most conditions a variation of not more than $\pm$ 120 feet could be expected at a point during the summer months although the pattern of fixed errors over the area of Liverpool Bay showed considerable variations for different sites.

The results were good enough though for it to be considered worthwhile fitting receivers in the salvage tender *Vigilant* and, later, in the *Salvor* to enable the system to be used for sweeping operations.

3. — Use of Decca in search for crashed aircraft

The system proved its worth in an incident in October, 1958, when an English Electric Canberra aircraft crashed into the sea about ten miles off Blackpool in about 15 fathoms of water. As it was the prototype of a new model, it was considered of the utmost importance to recover the aircraft to determine the cause of the crash. As no naval surveying vessels were immediately available in the vicinity, the Mersey Docks and Harbour Board were asked if they could assist.

Not having an asdic-fitted vessel, the only hope was a close echo sounding survey or a very lengthy bottom sweeping operation, the position of the crash being known only to within about 1.5 miles, this by plotting back from the position in which a Decca-fitted fishing vessel picked up the pilot who had baled out before the crash. It was decided to try the echo survey first and it was clearly necessary to fix the ship with great accuracy if the area was to be systematically covered. Shore fixing was very doubtful at that distance from land and the only alternative to Decca would have been a system of floating beacons but the fixing of these would have presented some difficulty in the absence of taut wire gear.

The most sensitive Decca pattern in the vicinity is the green with slave at Neston in Cheshire and the red pattern gives a good cut with it. A rough plotting sheet was therefore made by graphically enlarging the lattice on Admiralty Chart L(D3)1981 to a scale of 1/6 000.

Two survey vessels were employed, one commencing at the north limit of the area and one at the south, and lines of sounding .05 green lane apart were run across the area. This represented lines about 100 feet apart on the ground and whilst, with the narrow beam echo sounding oscillators fitted, this gave less than 50 % coverage of the seabed. It was anticipated that, as the aircraft had almost certainly broken up, there was a fair chance of locating something even though each piece would be a very small target.

Fortunately, the seabed in the vicinity proved to be quite smooth and in the event, with a certain amount of good fortune on the third line run from south, a small lump projecting about 4 feet above the seabed was detected, a dan buoy laid on it and its Decca co-ordinate noted. The weather was unfit for diving operations at the time and an attempt to identify the echo was postponed until next day. During the night the dan buoy had disappeared so that a drag sweep was run over the area centred on the Decca position. The sweep snagged at the position of the original contact and a diver went down and found a piece of the aircraft with the sunken dan buoy alongside it. This piece was recovered and it was noted that when the salvage vessel was over the spot, the Decca co-ordinates were identical with those of the contact of the previous day. The piece of aircraft turned out to be a section of wing approximately 20 ft × 10 ft × 1 ft 6 ins. It had been standing on its broken edge and was, therefore, an extremely poor echo sounding target.

During successive days, further pieces were detected as very close lines were sounded to the north of the original contact. The Decca co-ordinates of each were noted though bad weather prevented further diving. At this stage, Naval Salvage took over the task of recovery as the Mersey Docks and Harbour Board vessel was required for other duties. A Decca-fitted survey tender, however, remained to work with the Admiralty salvage craft. In addition, two Decca-fitted seine netters were chartered and contacts by echo sounding or by snagging with the trawl were buoyed and dived on. By this means, about 75 % of the aircraft was recovered, including the recording instruments in use during the fatal trial flight and, also, the body of the navigator.

During the operation no attempt was made to arrive at absolute Decca errors, but the repeatability of the system appeared very satisfactory so that once a contact had been fixed by the Decca co-ordinates, it was possible to re-locate it without great difficulty.

4. — Radar as an aid to survey

At about this time, consideration was given to whether radar would be used as an aid to surveying on the scales required. A new harbour control radar system was installed at the end of 1958 to cover the approaches to Liverpool. At the same time a ship-borne survey radar had been developed for the Royal Navy which enabled the accurate ranges of two targets to be read off simultaneously without stopping the rotation of the aerial.

One of the main advances in the new Decca Type 32 Harbour radar was the introduction of " interscan ". This enabled the operator to give the position of a target accurately in relation to any other target on the display and meant that a survey launch's position could be given by a bearing and distance from a co-ordinated point such as a beacon or a wreck mast. However, the method of controlling a survey launch from ashore was considered too cumbersome. The accuracy obtained from one range and bearing would not be sufficient for the 1/6 000 scale and, in any case, the radar would probably be in use to assist shipping on a large number of occasions when visibility was too bad for shore fixing. A further drawback was the long period of setting up of the shore radar (several hours) to achieve surveying as opposed to navigational accuracy.

With regard to the ship-borne survey radar, such as the Decca Type 979, the accuracy claimed of ± 25 yards was insufficient for large scale work. Also the equipment was too bulky to enable it to be fitted in the survey tender *Aestus,* and rather expensive for a single user system.

5. — Difficulties with navigational Decca

In 1958 and 1959 continued use was made of the Decca Navigator system for work on small scales and, occasionally, the green pattern used in conjunction with an angle between shore marks for the 1/6 000 surveys.

In October, 1959, some difficulties began to be experienced with the equipment. To enable the North British chain to be used in conjunction with Decca Navigator Mk. 10 by aircraft crossing the Atlantic, an additional lane identification signal was introduced which had the effect, as far as the Type 375 survey receiver was concerned, of producing a series of kicks on the decometers lasting for about 13 seconds with only 7 seconds in between. Apart from the inconvenience of fitting fixes into this short period, there was no certainty as to when the kicks started as, with a vessel moving at a reasonable speed and, say, the decometer rotating clockwise, the first effect of the kick could be merely to increase the speed of its rotation momentarily before it obviously kicked the opposite way, and during this period a false reading could be obtained. A method was developed by the Decca Company of indicating when the lane identification signal was being transmitted and it was arranged that the red light on top of the decometer dials would burn during these transmissions and fixes could safely be taken whilst it was extinguished.

Whilst this made it possible to use the system, it was far from satisfactory and enquiries were made as to an alternative method of fixing for surveying in poor visibility.

6. — Trials of Hi-Fix

A system offered by Decca was a development of the Navigator and was given the name Hi-Fix. It worked on a higher frequency (about 2 Mc/s) than the conventional Decca and all transmissions were on the one frequency on a time sharing basis so that the baseline lane width was a constant figure. All the components had been miniaturised and the system designed to work from a 24-volt battery so that each station was entirely portable. Of course, this low power supply meant a reduced range (up to 40 miles). It was agreed to carry out trials with this equipment in the summer of 1960 in Liverpool Bay.

In preparation for this, sites were selected for the master and two slave stations. It was known that each station was housed in a lightweight trailer so that one requirement of the sites was reasonably easy access from a road. Another requirement was that the cut of the hyperbola generated by the system should be reasonably good in the trial areas. Further, it was

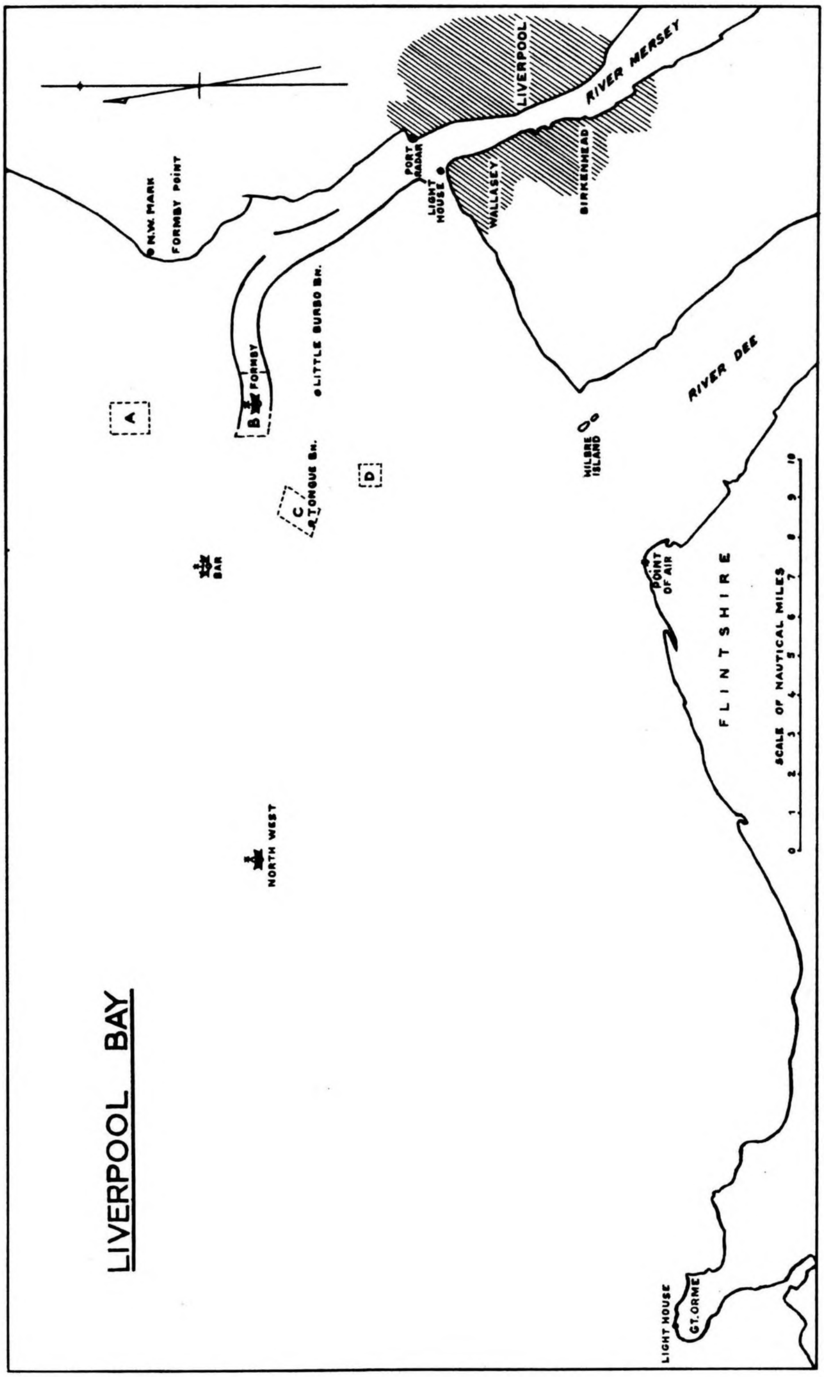

Fig. 1. — Areas of Hi-Fix and Hydrodist trials.

desirable that the sites should be either close to, or visible from, co-ordinated marks so that the problem of fixing them accurately should not be too great.

The positions finally selected were the master station on top of the roof of the port radar station at Gladstone Dock, slave one on the foreshore at Formby, and slave two on Hilbre Island (figure 1). All these sites had the added advantages of having telephone communication immediately at hand which avoided complications of radio communication.

A number of trial areas were selected in Liverpool Bay, the method of comparison being to construct a Decca lattice on astrafoil to cover areas for which sextant angle plotting sheets were already available on a scale of 1/6 000 or larger. In this way, by taking simultaneous Decca readings and horizontal sextant angles, a visual comparison of the fixes could be made by superimposing the plastic sheet over the sextant angle working sheet. It was realised that this method had its limitations. It had, however, a number of advantages. Firstly, it enabled a direct comparison to be made without the delay and labour of calculating the co-ordinates of the fix and converting to a theoretical Decca value. Secondly, with the prevailing poor visibility conditions in Liverpool, it was thought very likely that on the day of the trials it would not be possible to fix a vessel by theodolite from the shore, whilst it might be possible to fix by angles between marks such as wrecks' masts or Admiralty navigational beacons, taken from the ship. The accuracy of the sextant angle fix obviously would not be of the same order as a theodolite intersection, but in the area chosen for the main trial, with the marks about two miles distant, it was calculated that an error of 1 minute in the sextant angle would result in a movement of the fix by 2.5 feet. Assuming this error in each angle and allowing a small error of distortion of paper, etc., of the two plotting media, it was considered that the fix would still be of the order of $\pm$ 10 feet at worst, provided that the sextants were carefully checked for index error before using and that the vessel was only moving very slowly whilst fixing.

The actual trial was carried out in June, 1960, with a receiver fitted to the salvage/surveying tender *Vigilant* (figure 2). As anticipated, visibility was poor throughout the trials, and for a week varied between two and four miles. This enabled fixing to be carried out in the various areas but not all on the same day and, in the vicinity of the Tongue Beacon, resort had to be made to fixing by bearing and distance from the beacon instead of fixing on three shore marks.

The procedure used was for the vessel to steam out to the first trial area and, by taking a number of shore fixes with the Hi-Fix equivalents, to obtain an average difference for each pattern. The whole lanes were then set correctly on the receiver and a correction passed by R/T to each slave station to apply a decimal correction at the slave to make the Hi-Fix reading at the receiver agree with the theoretical value from the shore fix. Thereafter, during the next few days as the weather allowed, a large number of shore fixes were taken with their Decca equivalents and the difference noted. A number of instrumental defects occurred at the slave stations, mainly in transistors which overheated and also with earth wires becoming disconnected. These accounted for the large alterations in the mean error at the same site at different times.

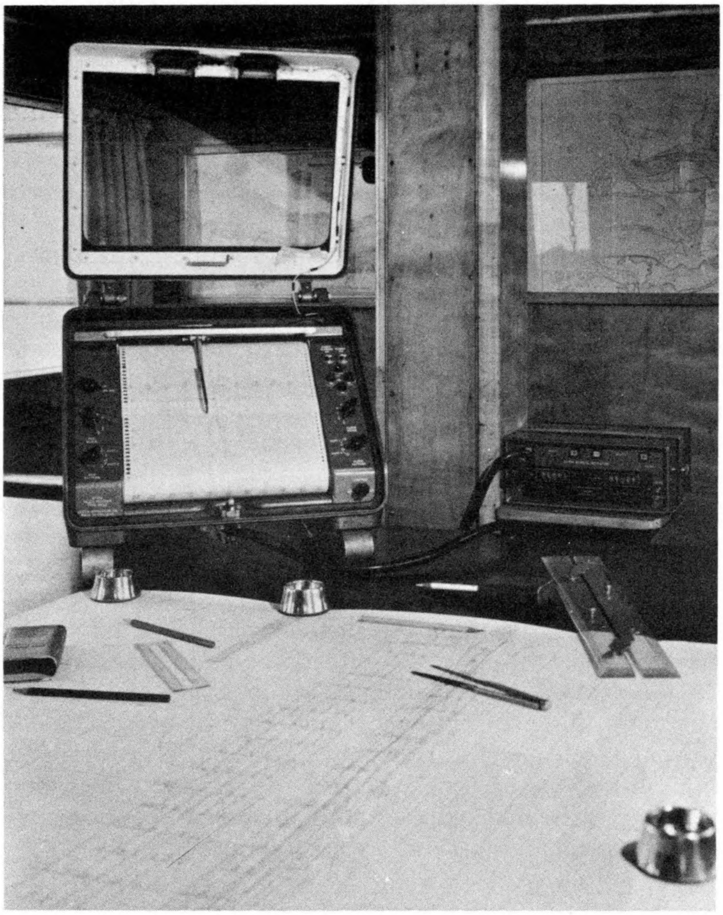

FIG. 2. — Remote display and Hi-Fix track plotter in S.T. *Vigilant*.

Discounting these errors, the fluctuations of differences about the mean value indicated that a fix of the order of ± 20 feet might be expected for about 75 % of the time, and it was claimed by the Company that a permanent installation would achieve better results still.

7. — Trials of Hydrodist

In July, 1961, trials were carried out with an alternative method of fixing to the Decca system. This was " Hydrodist ", a development for marine use of the tellurometer which had proved an outstanding success for distance measurement ashore.

The main difference in principle between the two systems is that Hi-Fix measures the difference in phase between the master and slave transmissions as received in the vessel and works on pure c.w. at about 2 Mc/s, while Hydrodist employs a master station transmitting a carrier wave of 3 000 Mc/s which is modulated by a 10 Mc/s frequency. This modulated wave is received at the remote station and re-radiated from the transmitting system of the latter, and the difference in phase between the outgoing and incoming signal at the master instrument is measured. Thus two pairs of instruments give, in effect, two ranges and thus a " fix " of the master instrument position relative to the two remotes.

As the accuracy claimed of Hydrodist was of the order of ± 1 metre, it was necessary to devise a method of checking it by a system that could be expected to give at least that degree of accuracy. Whilst theodolite intersection would have provided this, there was, as with Hi-Fix, considerable uncertainty as to whether visibility would be good enough on the day of the trial.

The trial was designed to assess (*a*) the accuracy and consistency of the equipment at ranges approximating to those which would be required in practice and (*b*) whether it could be easily operated by existing personnel and whether its adoption would involve additional labour to operate the remote stations.

With this in mind, three sites were selected in Liverpool Bay in which to carry out comparisons of Hydrodist with visual fixes. One of these consisted of the area of the existing sextant angle plotting sheet for the Taylor's Spit section of the main approach channel. This was selected as a typical area where surveys are frequently delayed by poor visibility. It had the advantage that, provided visual fixing was possible during the trials, the marks (one wreck mark and two Admiralty beacons) were sufficiently close that any observational errors would result in a minimum ground displacement of the fix.

The other two sites were in the immediate vicinity of the two Admiralty beacons, Tongue and Little Burbo.

Positions were selected for the remote stations ashore to give a good cut of the range circles at these three sites, one on a tower locally known as Observation Tower at Formby, the actual station being an Ordnance Survey third order bolt, the elevation of which was approximately 60 ft above M.H.W.S. The other was at Grange Hill, West Kirby, close to a third order. Ordnance Survey pillar, 160 ft above M.H.W.S.

The existing sextant angle graph of the Taylor's Spit area was on a scale of 500 ft to 1 inch (1/6 000) and an overlay on permatrace was made to fit this, showing the range circles from the two shore stations. Although the scale of this was not sufficiently great for a critical comparison of accuracy, it was intended to give a rapid method of comparison and a convenient way of simulating normal survey lines to assess the ease of operation.

For a more critical comparison, a plot was made on a scale of 100 ft to 1 inch in the immediate vicinity of Tongue and Little Burbo Beacons. Range circles from the shore stations were drawn on the plotting sheet which also showed the position of the centre of the light on the beacon. The calculated transit bearings of each beacon and a selection of co-ordinated objects were drawn on the plot. The visual distance from the beacon was obtained by the vertical angle of a thirty-foot measured distance on the flagstaff on top of the beacon structure. The table of distances was calculated on the basis of the observer's eye being level with the base of the pole at half tide.

The vessel used for the trial was the Mersey Docks and Harbour Board's 750-ton salvage/buoyage/surveying tender *Vigilant*. The aerial was rigged on a temporary Dexion structure on top of the chartroom at a height of about 36 ft above the water, the instruments, including aerial control units, being placed on the after end of the chartroom table.

Test runs were made through the three areas on Monday, 3rd and Wednesday, 5th July. In the Taylor's Spit area, very close agreement was attained between the two methods of fixing, though no attempt was made on this scale to obtain differences for each fix.

The fixes in the vicinity of Tongue Beacon (40 in all) showed differences varying from 0 ft to 10 ft between the visual and electronic. The accuracy of the method of obtaining distance from the beacon could not be better than ± 5 ft and the actual fixing of the beacon not better than ± 1 ft. The fixes were taken by a standby-stop method as the ship slowly crossed each transit, so there was also a fractional possible time lag between visual and Hydrodist fix. With this in mind, it is difficult to say that the electronic fix is less accurate than the visual, and it may well be that it is the more so.

A smaller number of fixes in the vicinity of Little Burbo Beacon showed similar results. The maximum difference in this case was 12 ft but, as a list has developed in this beacon since its original fixing, its position could only be said to be accurate to about ± 4 ft. Also due to the list, the 30-ft pole, when viewed from one side, would be slightly foreshortened and thus give a slight range error.

On the final return passage through the Taylor's Spit area, the opportunity was taken to use the Hydrodist to assess the error of the navigational Decca system in that vicinity as a Decca gridded plotting sheet for the same area already existed. Twelve fixes gave an average of Red ± .14 and Green ± .11 to be applied to the decometer readings with a variation of ± .01 on the range. This was in close agreement with the average Decca error previously obtained by visual fixing over a period of years.

On the Tuesday, with gale force winds making an accurate sea trial impracticable, the opportunity was taken to measure the distance between the two shore stations with one of the pairs of Hydrodist instruments. The 'true' distance calculated from co-ordinates between two Ordnance Survey stations was 19 235.41 metres and the Hydrodist gave 19 235.05 metres.

On Thursday, 6th July, demonstrations were given a.m. and p.m. in the Taylor's Spit and Tongue Beacon sites to representatives of other interested authorities.

From the user's point of view, the interpretation of the tens and units figures of each range and the following of the bright spot with the cursor presented no difficulty at all for those accustomed to visual fixing. The method of eliminating ambiguity of the hundreds and thousands digits (equivalent to lane identification) was mastered after a short time and it was only the aerial training that presented any difficulty. Keeping these aligned approximately on the shore stations after frequent alterations of course required close co-operation between the officer conning the ship and the Hydrodist operators and, even so, with the aerial only having a 400° arc of traverse, it was rather easy to come up on the stops after a large alteration just as a fix was required, and the slow rotation of the aerial could cause a slight delay in obtaining the first fix of the new line.

On shore, little difficulty was experienced and it was considered that an intelligent seaman, after a short training, would be able to switch on and operate the equipment for normal running. One battery was found to last for about a day and a half of normal working.

There is a requirement for someone to be in attendance on each remote instrument as, apart from an occasional minor adjustment, it is necessary to keep the aerials trained approximately on the survey area and, though one heading would probably suffice for a localised survey, the direction of the aerial would require adjustment for subsequent surveys.

This would appear to entail either sending a seaman out to each remote station for the period of operation (this would not be convenient at Liverpool in view of the distances involved) or siting the remotes in such a place that a local individual could be employed when required, to switch on and off, keep aerials trained and other minor adjustments, and arrange for batteries to be charged overnight.

8. — Decision to purchase Hi-Fix

After considering the results of the trials of Hi-Fix and Hydrodist, a decision was made to purchase Hi-Fix for the following reasons :

(*a*) Whilst Hydrodist undoubtedly gave the more accurate position, it was a single-user system and for the purposes envisaged, at least three ships were required to be fitted. To enable this to be done with Hydrodist, three complete sets of instruments would be required, which would be very cumbersome to operate.

(*b*) The Hi-Fix shore stations were entirely automatic requiring only a non-technical attendant in the vicinity, whilst the Hydrodist aerial, being directional, required training continuously onto the appropriate bearing of the receiving vessel.

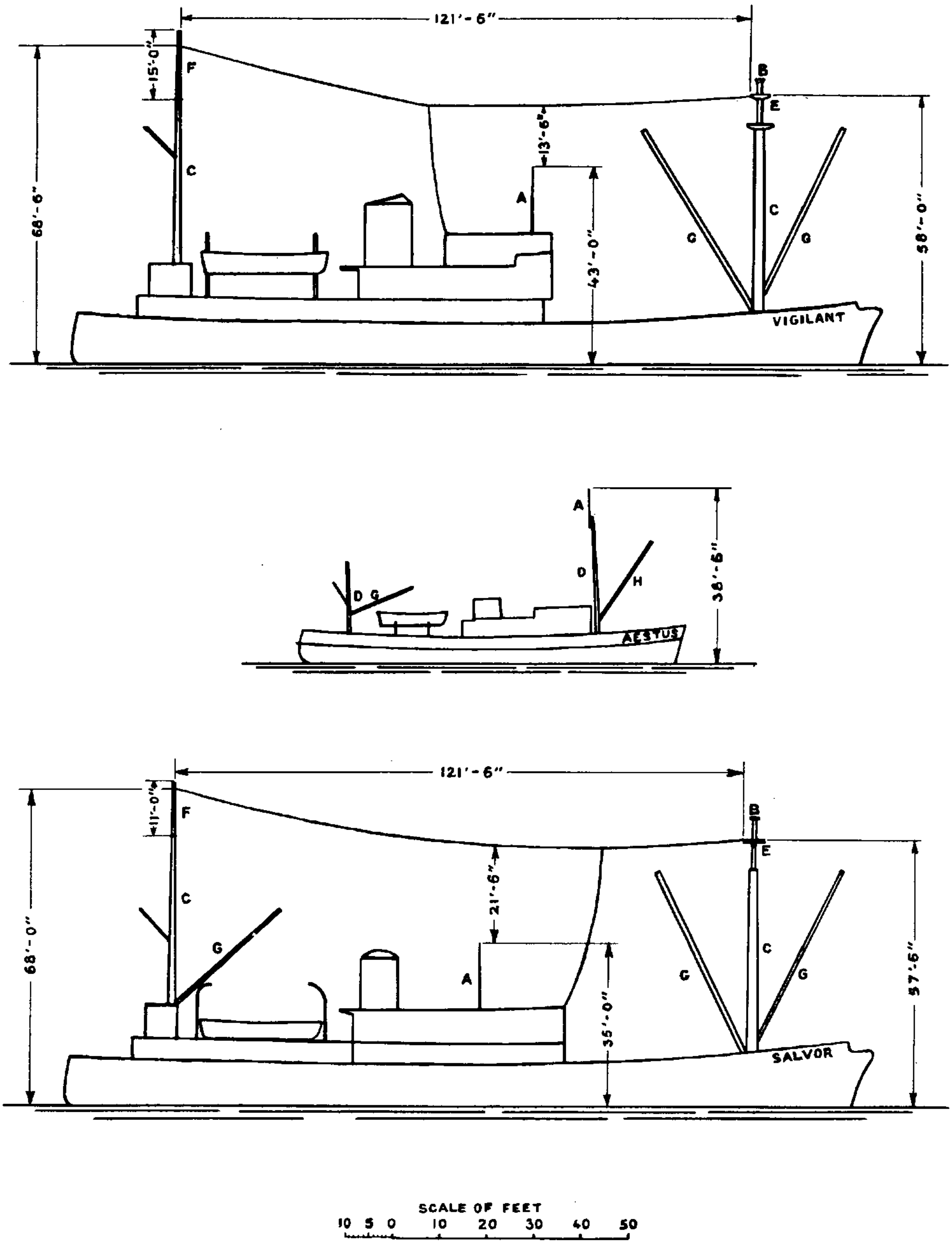

FIG. 3. — Profiles of vessels showing aerial positions.

A : Hi-Fix aerial	B : Radar scanner
C : Steel mast	D : Timber mast
E : Steel topmast	F : Timber topmast
G : Steel derrick	H : Timber derrick

(*c*) The Hydrodist, working as it does on a radar frequency, has a line-of-sight range limitation which meant that with the height available for the shore installations, it would not be possible to cover the whole of Liverpool Bay.

9. — **Installation of Hi-Fix**

An order was placed in September, 1961, for a Hi-Fix installation with four receivers, i.e. for the Board's vessels, *Vigilant, Salvor* and the survey tender *Aestus* (figure 3) together with one for the Westminster Dredging Company's vessel *Mersey* which was engaged in a long-term dredging contract for the Board.

Consideration was then given to the question of sites for the shore station as permanent installations. The main requirements were as follows :

(*a*) Mains power available.
(*b*) Open site clear of overhead wires or mobile structures.
(*c*) Non-technical personnel available in vicinity for supervision of equipment.
(*d*) Sites in positions to give pattern of hyperbolae which will provide most accurate fixing in the sea channel approaches, as well as adequate fixing in the remainder of Liverpool Bay.
(*e*) Sites should be as close to the coast as possible to avoid mixed land/sea paths either from master to slave or between shore stations and ship's receivers.

Clearly, it was unlikely that all these requirements could be met in full, but eventually the best compromise was with the master station on the reclaimed land north of Gladstone Dock, one slave in the coastguard lookout at Formby and the other in the Board's Lighthouse at Great Ormes Head (figure 4). The latter involved a baseline of about 31 nautical miles and this was near the limit for the equipment but it was considered possible, in view of the height of the lighthouse, and had a great number of advantages, particularly the fact that there was a caretaker in attendance, that it was on Mersey Docks and Harbour Board land, and was right away from any form of interference.

The actual position of the 32-ft transmitting mast at each site was then decided upon, as the calculation of the position of the Decca grid depended on the co-ordinates of these masts. The fixing of each of these points presented a different problem. The accuracy required was about .1 metre.

At the master station an Ordnance Survey traverse point existed about 200 ft away from the site and visible from it, so that it was possible to observe an angle at the traverse point between a main station and the mast position with a taped distance to it with the required accuracy.

The proposed Formby slave station was to be situated among the sand dunes on the backshore and would have been difficult to intersect from

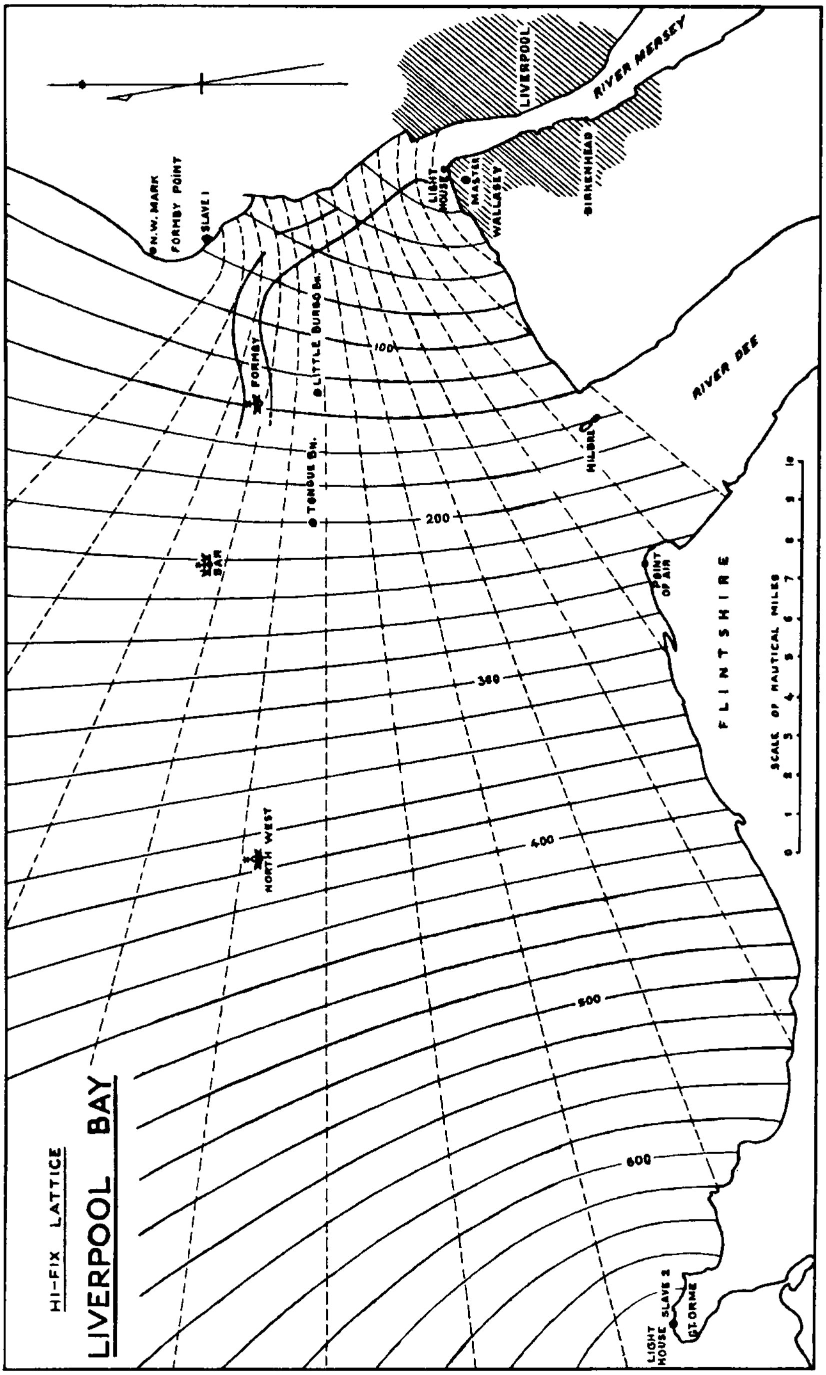

Fig. 4. — Coverage of Hi-Fix in Liverpool Bay.

enough co-ordinated points without going across to North Wales, which was too great a distance for accuracy or visibility. However, there was an O.S. bolt on a tower about 1 200 ft away. A normal traverse from this would have been difficult over undulating sandhills but a tellurometer was available which enabled a direct measurement to be made which only required correcting for slope. As a further check, the mast site was fixed by semigraphic resection, using all the co-ordinated marks visible.

At the Great Ormes Head site, the only O.S. station nearby was a permanent traverse station on the hillside about 200 ft above the lighthouse. The site could not be intersected as the lighthouse was not visible from any Trig. station except, possibly, one in Anglesey. It was not directly visible from the permanent traverse station mentioned, as a shoulder of the hill interrupted the line of sight. However, from the shoulder of the hill, both the permanent traverse station and the mast site were visible and also an O.S. pillar on the summit of the Great Orme. A short base (100 ft) was taped along the brow of the hill approximately at right angles to the line joining the permanent traverse station to the mast site; the terminals being marked by ranging poles.

A theodolite was set up at the mast site and carefully levelled and the subtended angle between the ranging poles carefully measured by the repetition method. The theodolite was then set up at the permanent traverse station and again the subtended angle between the ranging poles was observed in the same way. In addition, the angle between the O.S. pillar and left-hand end of the base was measured. At the left-hand end of the base the slope of the base was noted, and the angle between the permanent traverse station and the mast site. The co-ordinates of site were then calculated as for a traverse. The accuracy was considered to be within the .1 metre required.

A certain amount of constructional work was required at the three sites.

For the master station, a building was erected to house the master oscillator, distribution and transmitter units together with batteries, charger, etc. Although each component was small (approx. 20 × 14 × 10 inches) the building was made sufficiently large (approx. 8 × 6 × 6 feet) to enable it to be used as a workshop for minor repair work, where it was necessary to use the master control unit to check a receiver.

The transmitting aerial was erected on the roof of the building, which had an additional advantage of lifting it over the screening of the 8-ft high, plastic-covered, open-link fencing surrounding the site. An earth system consisting of 24 radial copper wires 50 ft long was led down the side of the building and then laid out flat and buried about 6 inches.

The equipment for the slave station at Formby was housed in the base of the coastguard lookout where there was already a power supply. The transmitting mast was erected about 200 ft north and the receiving mast about 200 ft south of the lookout (figure 5), each having a radial copper wire earth mat as for the master station. The ends of five of these radial wires of the transmitting mast were joined to the ends of a similar number from the receiving mast to provide a stabilized earth system. A small hut was erected at the base of the transmitting mast to house the transmitter unit.

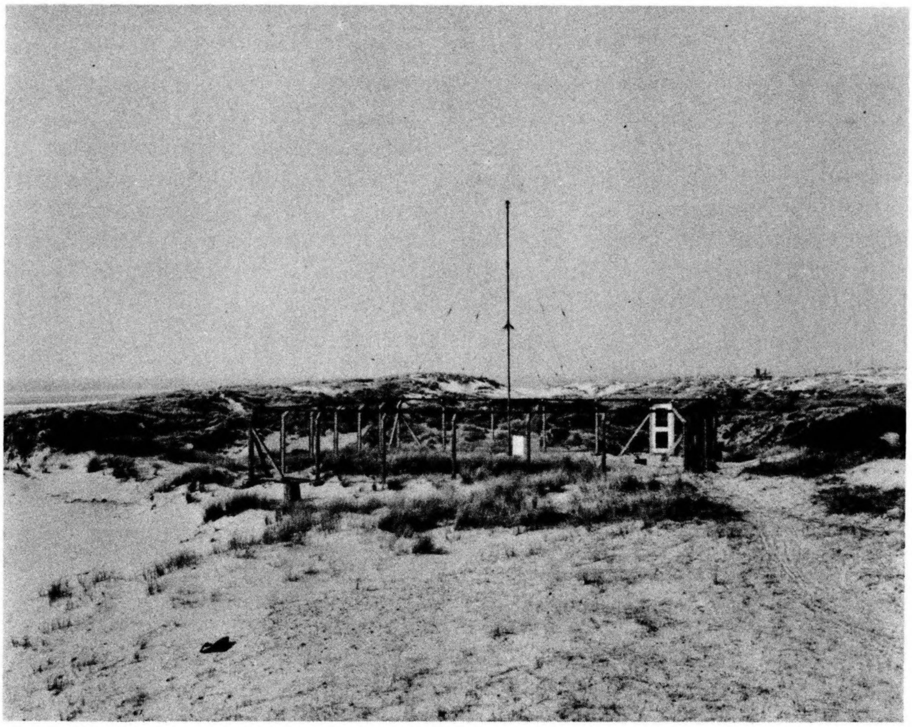

FIG. 5. — Slave 1 transmitting mast at Formby.

At Great Ormes Head, the equipment was placed within the lighthouse building, the transmitting mast being on an area of flat grass in front of the building (figure 6) and the receiving aerial on the roof, the associated earth mats being joined by copper wires fixed to the outside of the building. Whilst there was no mains power at the lighthouse, it had its own generator which was sufficient for the time being but, in any case, arrangements were in hand for providing a mains supply in the future.

A monitor receiver was fitted in the Port Radar Station in a position where it was continuously under the duty operator's eye. The aerial for this receiver was mounted on top of the 90-ft VHF tower adjoining the building.

The masts were erected and the equipment installed at the beginning of May and initial trials of the equipment commenced at the end of the month.

To arrive at initial setting up figures for the goniometers at the slave station, theoretical Hi-Fix values were calculated for the known positions of the receiving aerials at each slave and the monitor, i.e. the reading at slave one, was adjusted until the receiver at slave two and the monitor showed the desired readings, and similarly at slave two.

The only fixed marks in Liverpool Bay which can be approached closely with safety are the two remaining Admiralty navigational beacons,

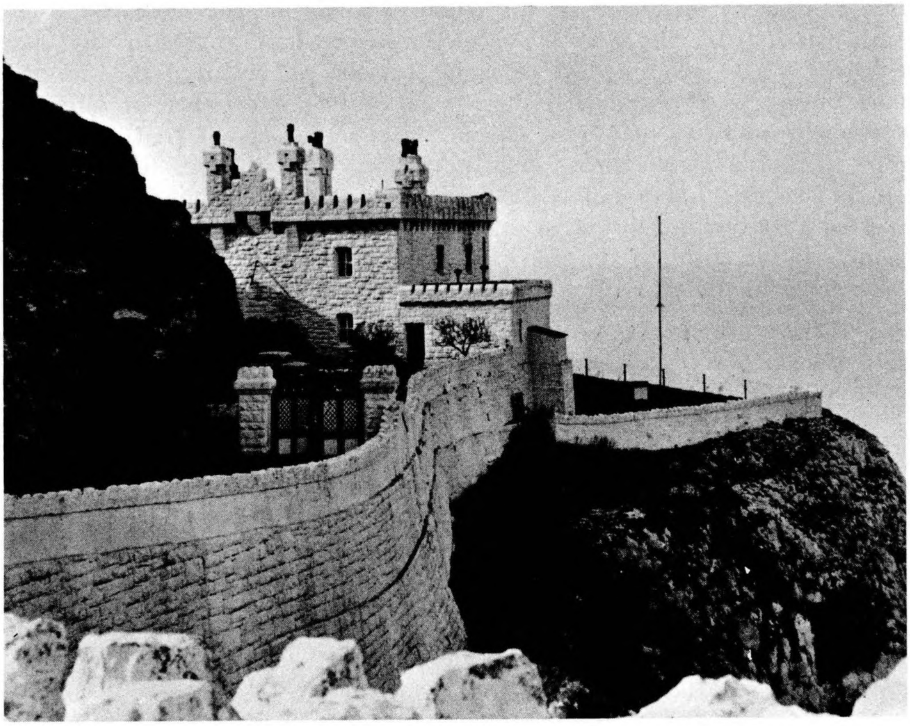

FIG. 6. — Slave 2 transmitting mast at Gt. Ormes Head lighthouse.

Tongue and Little Burbo. Hi-Fix values for these were calculated from their known national grid co-ordinates and a small plotting sheet on a large scale made for an area approximately 300-ft radius round each beacon. As it was not possible to place the vessel's Hi-Fix aerial nearer than about 100 ft from the actual beacon centre, it was decided to check each pattern separately. The vessel drifted past the beacons very slowly about 100 ft off and, when the bearing of the beacon for the Hi-Fix aerial was the same as the direction of the hyperbola of one of the patterns, that pattern reading was noted and similarly for the other.

Whilst this method could not be said to be absolutely accurate, the Hi-Fix error resulting from a compass error of $\pm 2°$ (providing the vessel was within 200 ft of the beacon) would be a maximum of $\pm .02$. This was considered quite good enough for the preliminary trials.

As a result of checks at these beacons, adjustments were made at the slave stations to produce a minimum error at the beacon positions. Then, on a suitable day of good visibility, a series of checks were made over a large area of Liverpool Bay.

Whilst for absolute accuracy it would clearly be desirable to have theodolites set up ashore and simultaneous observations made to the vessel with a corresponding Hi-Fix reading, in an area such as Liverpool Bay this would involve a large number of personnel and instruments to occupy enough sites to cover anything more than a very small area. It was decided therefore, as a first check on the whole systematic accuracy over a large area, to fix from the vessel by horizontal sextant angles using marks designed to give the greatest possible accuracy of fix, and to employ as many observers as possible, either to take a large number of objects or to duplicate observations as a check. It was appreciated that as the distance from the marks increased, the accuracy of the fix lessened, viz : with marks distant 10 miles, an error of 1 minute in one sextant angle involved a movement of approximately 18 ft in the fix and thus, depending on the relative siting of the marks, a maximum error of $\pm$ 25/30 ft might be expected in the fix.

All fixes taken were converted by semigraphic resection into national grid co-ordinates and thence to theoretical Hi-Fix readings using the formula :

$$\frac{\text{Master to Slave} + \text{Master to Fix} - \text{Slave to Fix}}{\text{Wavelength (157.627)}}$$

all in metres.

To simplify the task of calculating the resections and to strengthen the fixes without observing additional angles, all fixes were chosen to include a sensitive transit of two co-ordinated points. This meant that by assuming the vessel to be on the observed transit, the calculation became the simple problem of intersection rather than resection. Where possible, a group of three fixes were taken at each station.

Unfortunately, at the time of the first calibration the monitor recorder was not in operation so that a continuous check could not be kept on the performance of the chain during the day, except for periodical check readings.

The results of the calibrations were disappointing. At each position, including the beacons, there was a spread of about .09 in a series of observations and, taking a mean at each station, there were variations of up to .10 between various different positions in the Bay. A close observation of the goniometers in a stationary vessel indicated that the pattern was not entirely stable, one pattern running off a few hundredths and then slowly returning, and then the other likewise.

A careful check was made of all the equipment in the shore stations and the receivers afloat, and a number of minor faults rectified. By this time the monitor recorder was in action and from it could be seen short term fluctuations of up to $\pm$ .04 at times with additional long term fluctuations of $\pm$ .04 on pattern one (Formby slave) which clearly had a relation to the rise and fall of the tide, the maximum deflection occurring at the high water of a spring tide. This was not altogether surprising as the baseline ran for most of its length along the 25-ft dry contour and was, therefore, only " wet " at high tides. The magnitude of the fluctuation, however, was much more than anticipated.

At this stage it was difficult to determine from the monitor record how much of the fluctuation was due to local interference and how much was due to interference with the master station, and various experiments were carried out to separate the two.

The chain was run with all the mains switched off, without any improvement, which eliminated mains-borne interference. The monitor station was moved to another site temporarily which was well away from any power supply or physical obstruction. This produced a very much better result which, in the end, confused the issue as this trial was carried out on a Saturday and Sunday, but at the time it appeared to indicate that the trouble lay in the monitor site only. However, the monitor was returned to its original position and, after a number of minor defects had been eliminated, it was run for a period of a week. An examination of the recorder trace showed a remarkable variation of the amplitude of the interference at different times of the day. It was at a maximum from about 0800 to 1200 and 1300 to between 1700 and 1900. During the night and at weekends the interference was only about $\pm$ .01 or .02.

The master station equipment was then moved to the Formby slave site and pattern II only monitored at Formby and Port Radar. It was found to be stable within $\pm$ .01. Finally, the master station was replaced at its original position and an additional monitor set up on the Lancashire shore and also " Rustrak " recorders fitted to the receivers at each slave station. The system was operated for a few days (midweek) and the record traces compared. The additional monitor and each of the slave recorders showed variations during the day of up to $\pm$ .03 and the monitor at Port Radar up to $\pm$ .04.

This was considered to be conclusive evidence that there was interference with the master station itself, affecting the whole pattern and that the same source of interference had an additional effect on the Radar Station monitor which was close to the master. The actual source of the trouble was considered to be the mass of dockside cranes in the Gladstone system, some of which were only 350 ft from the master aerial. It was thought that a portion of the master transmission was being picked up by the crane jibs and being re-radiated and that the constant movement of the jibs during normal working hours created an apparent movement of the position of the master aerial.

10. — Movement of master station

The only solution was to find a new site for the master station. This was unfortunate as by this time all the charts and plotting sheets had been prepared to cover the various parts of the Bay on the appropriate scales. Also an alternative site was not easy to find. In establishing the stations, it had been considered desirable to have them as near the H.W. mark as possible and to get further from the dock system under these circumstances would have meant moving north along the Lancashire shore, thus reducing the length of the baseline. Also there was a great problem of physical security in an area subject to much vandalism, also the problem once more of laying on a power supply and building another structure to house the equipment.

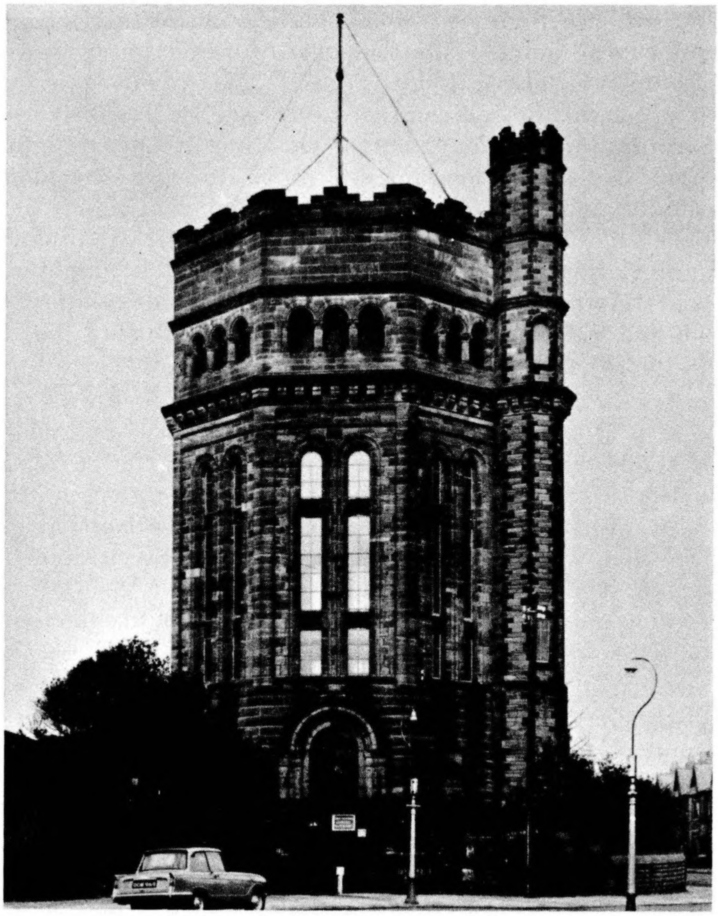

FIG. 7. — Master station at Wallasey.

An alternative position was to place the master on top of a large, flat-topped water tower which was the highest point in New Brighton on the Cheshire side of the river (figure 7). This appeared attractive as there was a power supply in existence, a caretaker in attendance during the day and little problem of physical security; also a complete absence of any sources of interference, either physical or electrical, with the transmissions. The only doubtful factors were that the tower was about 2 500 ft inland and that the size of its top would only be sufficient for a 20-ft radius earth mat. With regard to the first point, for most areas of Liverpool Bay the path from the master station to the survey vessel would cut the coast at a broad angle so that there would be little variation in the proportions of land/sea path. The second point was a disadvantage, but the open site and the fact that a good direct earth was available via the lightning conductor of the tower was considered to compensate for any deficiencies in the area of earth mat.

Before coming to a final decision, arrangements were made to install a temporary master station at the site and carry out a careful calibration to determine the improvement, if any, in the results. This was done during August, 1962, and on this occasion, when the main interest was in the stability of the pattern, it was decided to use theodolites for fixing the ship and accept that only a small area of Liverpool Bay could be covered. Six groups of fixes were taken, there being about one mile between each group. Approximately six observations were taken in each group. The actual method of fixing was for the vessel to anchor in the position required and the fix to be controlled by R/T. The point of intersection was the foremast which had sheets of " Dayglow " material wrapped round the top for identification. A note of the ship's head at the time allowed a correction to be made for the difference between the foremast and the Hi-Fix aerial. As an experiment a pair of tellurometers was used to obtain the range from the water tower to the ship, in addition to the theodolite angles, and this range from it superimposed on a semigraphic plot for each fix with satisfactory results. As before, the fixes were converted to Hi-Fix values and the results tabulated (table I). These showed agreement to a ± .02 between fixes in a group and to ± .03 on pattern one and ± .04 on pattern two between fixes over the whole area. During the calibration monitors at the slaves showed movements of less than ± .01. The monitor at Port Radar at the same time showed variations of ± .025 which indicated that there was still local interference, presumably from the cranes affecting that site, although of course no longer affecting the patterns as a whole.

It was therefore decided to move the master station, and arrangements were set in hand for the necessary authority to be obtained from the owners of the tower and the small amount of constructional work entailed. The greatest amount of work was in the recomputing and replotting the grid on the various scales. The new position of the mast was easily obtained as there was an O.S. bolt on the top of the water tower.

The actual movement of the master station was carried out in December, 1962. Further consideration had been given to the question of earthing, and the Company advised that initially the earth mat should not be connected to the lightning conductor as, from theoretical considerations, the latter, in view of its great length (about eighty feet) might if connected radiate in addition to the mast and, as it ran down the side of the building about twenty feet away from the mast position, might give an apparently false point of emission of the master transmission. The amount of the error would be difficult to predict as it would depend on the proportion of signal radiated by mast and lightning conductor.

TABLE I

Calibration of Hi-Fix with master station in trial position on Wallasey water tower

Fixes by Theodolite Intersection and Tellurometer Distance

Position	Fix	Hi-Fix Differences (Calculated minus Observed)	
		Pattern I	Pattern II
1	a	—.15	+.43
	b	—.12	+.43
	c	—.13	+.43
	d	—.13	+.45
	e	—.12	+.43
	f	—.12	+.44
2	a	—.10	+.46
	b	—.13	+.45
	c	—.14	+.46
	d	—.12	+.45
	e	—.13	+.47
	f	—.12	+.45
3	a	—.12	+.48
	b	—.14	+.49
	c	—.13	+.49
	d	—.15	+.48
	e	—.15	+.46
	f	—.13	+.46
4	a	—.13	+.45
	b	—.14	+.43
	c	—.12	+.46
	d	—.10	+.48
	e	—.14	+.43
	f	—.11	+.45
5	a	—.17	+.40
	b	—.16	+.40
	c	—.15	+.42
	d	—.16	+.43
	e	—.16	+.41
	f	—.15	+.42
6	a	—.15	+.43
	b	—.15	+.43
	c	—.16	+.42
	d	—.16	+.42

In view of this it was decided initially not to connect to earth but to add some extra radial wires to the earth mat to compensate for its loss in length, and to carry out experiments as soon as possible to determine exactly what was the effect on the patterns and the tuning of the master transmitter if the earth connection was made.

When the system was operating satisfactorily and this experiment was carried out, it was found in fact that connecting and disconnecting to the lightning conductor had no effect whatsoever and it was concluded that, as the actual prongs of the lightning conductor were spaced equidistant round the top of the tower and joined to the main earth connector by copper strips running across the top of the tower and passing over (although not touching) the Hi-Fix earth mat, an induced effect resulted which was as if a connection actually existed. In view of this and for the safety of the Hi-Fix equipment in the event of lightning striking in the vicinity, a firm connection to earth was finally made and this has proved quite satisfactory in practice.

Due to continuous poor visibility in January, 1963, it was difficult to obtain very refined checks on the accuracy of the system. The values obtained from the trial with the temporary master at the water tower were set on at the slaves, and checks by sextant angle indicated the errors were .04 or less on each pattern in the sea channels and approaches. This meant that the system was quite accurate enough for surveying on scales up to 1/6 000 as the errors involved only amounted to ± 20 ft. It was considered that the system might be capable of greater accuracy when it became possible to carry out a proper calibration.

11. — Maintenance

The maintenance of the chain and the ships' receivers is being carried out by radio engineers of the Mersey Docks and Harbour Board who have undergone a three-week training course with the Decca Company. These radio engineers would normally be employed on the maintenance of VHF radio equipment in the Board's vessels and shore stations, and, due to a recent reduction in the total number of these sets, it has been found possible to work in the maintenance of the Hi-Fix equipment without taking on extra staff. The monitor receiver was ultimately moved to the radio workshop so that it was under the eye of the maintenance staff.

12. — Meteorological effects

When all the " teething troubles " of the equipment had been eliminated, some effects of different weather conditions became apparent.

Unlike the " conventional " navigational Decca systems there is no apparent sunset or sunrise effect, or reduced accuracy due to skywave at night. This is presumably due to the higher frequencies and shorter ranges involved.

The temperature of the equipment is a critical factor in its efficient operating. It had previously been discovered that overheating of components occurred under summer conditions when the units were housed in the heavy transit cases supplied, and the equipment was modified to include a blower unit. During the exceptionally cold weather in early 1963, however, the slaves were found to be going out of lock at frequent intervals due to the blowers keeping the temperature too low and it has been found that the blowers are not required during normal winter operating conditions when the equipment is housed in an unheated compartment.

The system is very sensitive to thundery conditions in the vicinity of the slave stations and, though there may not be audible thunder, if there is much static audible on a normal radio receiver in the 1 900 kc/s band it will be found that although the master station signals are being properly transmitted the slave stations may not be able to distinguish the trigger pulse from the static and the slave will go out of lock.

A similar effect is noticeable with some types of rain. It has been established that while general light rain over the whole area has no effect on the system and local rain at a ship receiver seldom causes trouble, local heavy rain squalls, even though not accompanied by electrical storms, do cause instability, particularly when they are situated on the baselines near the slave stations or, less frequently, when they are between a slave and a ship receiver. Inspection of the equipment at a slave station during the passage of one of these rain squalls has shown the strength of the signal from the master station fall to zero and then come back to full strength as the rain crossed the visual line of sight along the baseline.

With the slave stations as they are situated in the Mersey Docks and Harbour Board chain with a baseline of 30 miles for slave II and only 7 miles for slave I, it is apparent that pattern II is affected much more frequently than pattern I by both electrical storms and rain storms so that the length of the baseline is clearly a contributory factor.

Whilst the disturbance of the pattern is usually of short duration and not in itself a serious problem, the question of lane identification presents some difficulty. During these periods of instability, lanes are either gained or lost, the number depending to some extent on the course and speed of the surveying craft. With a lane width of between 300 and 500 feet, as is the case in most of Liverpool Bay, it is often difficult to reset the lanes accurately when in open water. Unless visibility is good enough to obtain a shore fix it is either a matter of setting up as accurately as possible and then checking the lanes on the return passage to port, replotting the work if the lanes are found incorrect, or steaming to an object of known position, buoy, lightship, beacon, etc., and resetting before carrying on with the survey. Either method is likely to be time consuming, which the equipment is designed to avoid.

Taken over a long period, however, the incidence of instability from this cause is very low.

13. — Final calibration

During May, 1963, a calibration of the system was carried out in an attempt to determine the Hi-Fix "error" over an area of Liverpool Bay. From sextant angle fixes it was known that this variation was small but it was considered desirable to have a more critical calibration by theodolite intersection from ashore. Groups of observations were made at eleven selected points in Liverpool Bay, the operation being controlled by R/T.

Because the distances were considerable and the visibility only moderate, the *Vigilant* was used in order to provide a more conspicuous target and her foremast with strips of " Dayglow " material secured round its upper platform as the actual point of intersection. As however, in this vessel, the Hi-Fix aerial was sited to be more or less vertically above the echo sounding oscillators and was not, therefore, at the highest point of the ship, it was thought possible that her masts and superstructure might produce re-radiations of the signals from the shore stations which might produce small variations in Hi-Fix "error" with the ship's head (i.e. with different relative bearings of the shore stations). With this in mind, at some of the positions occupied, observations were made with the ship on a number of different headings, and additionally, to check the effect of the vessel's M.F. aerial, observations were made both with this erected and removed.

The results of the calibration are tabulated (table II). During the period in question, the pattern readings at the opposite slaves were as follows :

Pattern II reading at slave 1 : .02 (± .01).

Pattern I reading at slave 2 : .82 (± .01).

These observations indicated that there was an effect due to ship's head and suggested that it was greater the nearer the receiver was to the baseline. Further experiments were carried out to prove this after the mean corrections found from the calibration (i.e. — .04 on pattern I and — .07 on pattern II had been applied to the slaves). It was found that on the pattern I baseline extension, where the ship was turned through 360° and the pattern I reading noted at 10° intervals, that a value of 159.245 (± .01) was constant for each heading. On the pattern I baseline a similar trial showed the calculated minus observed values to vary from + .08 to — .08 on swinging the ship from heading to the slave to heading to the master, with a zero value with the stations on the beam in either sense.

From this and the results of the main calibration it was concluded that, with the M.F. aerial down, the effect of mast and rigging was that of moving, the actual point in the ship being fixed from the site of the aerial to a point approximately 20 ft further aft and, with the aerial erected but earthed, this distance was 30 ft. These, being constant calibration factors, can easily be allowed for in practice.

TABLE II

Results of theodolite calibration

May 1963

Position		Ship's Head	Hi-Fix Differences Calculated minus Observed		Position of Ship's M.F. Aerial
			Pattern I	Pattern II	
1	a	127°	—.04	—.11	Down
	b	126°	—.07	—.11	
	c	123°	—.09	—.16	Up and earthed
	d	125°	—.10	—.15	
	e	125.5°	—.08	—.14	
2	a	112°	—.04	—.12	Down
	b	110°	—.04	—.10	
	c	109°	—.04	—.09	
3	a	084°	—.01	—.10	Down
	b	088°	—.03	—.11	
	c	089°	—.05	—.11	
4	a	067°	—.04	—.11	Down
	b	068°	—.04	—.13	
	c	072°	—.05	—.08	
5	a	050°	0	—.09	Down
	b	048°	0	—.08	
	c	049°	0	—.07	
6	a	052°	+.01	—.10	Down
	b	052°	+.01	—.07	
	c	053°	+.01	—.09	
7	a	135°	—.05	—.07	Down
	b	102°	—.04	—.12	
	c	040°	—.03	—.09	
	d	314°	—.01	—.03	
	e	281°	—.01	0	
	f	264°	—.02	—.01	
	g	252°	—.02	—.01	
	h	206°	—.07	—.01	
	j	168°	—.06	—.06	
	k	131°	—.06	—.07	
	l	092°	—.04	—.11	
	m	340°	+.01	—.03	
	n	275°	—.02	+.01	
8	a	055°	—.05	—.14	Down
	b	059°	—.06	—.13	
	c	057°	—.07	—.13	
9	a	124°	—.07	—.07	Down
	b	126°	—.08	—.08	
	c	132°	—.08	—.11	

Position		Ship's Head	Hi-Fix Differences Calculated minus Observed		Position of Ship's M.F. Aerial
			Pattern I	Pattern II	
	d	016°	+ .01	— .10	Up and earthed
	e	325°	+ .05	0	
	f	277°	+ .01	+ .04	
	g	228°	— .07	— .01	
	h	179°	— .12	— .06	
	j	147°	— .13	— .11	
	k	102°	— .09	— .17	
	l	089°	— .06	— .19	
	m	048°	— .03	— .15	
10	a	341°	— .04	— .05	Down
	b	311°	— .06	— .05	
	c	268°	— .06	— .04	
	d	011°	— .04	— .10	
11	a	205°	— .07	— .03	Down
	b	209°	— .10	— .07	
	c	209°	— .09	— .04	

By applying this correction to the values obtained in the theodolite calibration, it was found that the maximum errors over the whole area were reduced to ± .03 lane, which would mean that a fix of the order of accuracy of ± 10 ft could be obtained in the main channels where the hyperbolae were closest together, and ± 20 ft anywhere in Liverpool Bay.

14. — Use of computer for calculations

An I.B.M. 1401 computer was installed in 1963 in the department of the Principal Accountant to the Board, to mechanise all aspects of wages, salaries and other accounting procedures.

To speed up the problems of the final calibration of the Hi-Fix installation in different vessels, where a large number of calculations were involved, converting from observed angles to equivalent Hi-Fix values, a program was developed to make use of the computer. In the case of sextant angle fixes (where as many objects as possible were observed), the program was written to solve the resection problem by a method of least squares (viz: *Survey Adjustment and Least Squares* by H. F. RAINSFORD, pp. 167-169).

A program was also devised to enable additional plotting data to be obtained for gridding areas not covered in the original layout or where coverage of existing areas was required on a large scale.

15. — Conclusions

The Hi-Fix installation has already proved its worth for such events as the arrival of a tanker drawing 46 feet where accurate, up-to-date surveys were essential and, whilst the cost of the equipment is considerable, it is considered that in a port the size of Liverpool some sort of radio aid to surveying is necessary in these days. As radar is used more fully, vessels are prepared to move in conditions of poor visibility and it is essential to be able to make up-to-date surveys under these same conditions. Also, with the increasing cost of operating the buoyage tenders which are also used for wreck sweeping and some surveying, it is vital to make maximum use of their working hours in as efficient a manner as possible, and an intelligent use of Hi-Fix should cut down, to a considerable extent, time wasted due to poor visibility.

It is clear, however, from the various problems that have arisen that Hi-Fix is very sensitive to both electrical and physical interference and that a very high standard of maintenance is required. Great care must be taken in the siting of the shore stations and the positioning of antennae in the vessels using the system if the theoretical accuracy of the equipment is to be achieved in practice.