RADAR CHART-MATCHING DEVICES

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1. INTRODUCTION. The usual method of using radar for navigation at sea is to transfer the information from the PPI to the chart. In many instances, however, the pilot will con the ship directly from the PPI, using his local knowledge, which is equivalent to using a chart impressed on his mind. In such cases it is necessary to identify immediately and unambiguously the PPI paints, which often bear little resemblance to the shape on the chart of the feature which is producing the echo.

In pilotage, which is interpreted as navigation in estuaries and harbours, where the hazards are close, there is not time for the normal method of fixing positions by laying off bearings, and it is usual to follow directions marked by buoys, leading marks or other local devices to bring the ship safely to its berth. Pilotage in fog, when the local marks are no longer visible, must depend on an instantaneous appreciation of the ship's position in relation to the nearest danger and to other ships. The PPI gives this information and it is really only necessary for the pilot to familiarize himself with the appearance of the PPI picture at each point in his waters, acquiring a special PPI sense, for him to extract the information he wants from it.

Table 1 shows the requirements for position-fixing systems formulated by the Second International Meeting on Radio Aids to Marine Navigation (1947), and it will be seen that the accuracy stipulated for an aid to harbour entrance is ± 50 yards.

TABLE I
THE REQUIREMENTS FOR POSITION FIXING SYSTEMS

Function	General order of depth of water	Distance from nearest danger	Order of accuracy required	Order of time available to obtain position
Aid to ocean navigation	Over 100 fathoms	Over 50 miles	± 1 % of distance from danger	15 minutes
Aid to approaching land; coastal navigation and port approach	20-100 fathoms	Between 50 miles and 3 miles	± ½ mile to 200 yards	5 minutes to ½ minute
Aid to harbour entrance	Up to 20 fathoms	Less than 3 miles	± 50 yards	Instantaneous position and track required

The same meeting also recommended strongly that « a suitable device be developed to provide accurate and positive identification by radar of navigational markers, dangers and shore features... that reflectors should be installed on selected navigational markers in order to facilitate the differentiation of these markers from other echoes, including sea return » (para. 8) and concluded that « a chart comparison unit is a desirable but not essential auxiliary device ».

The difficulties of identification of echoes implicit in this recommendation are well known and attempts to reduce them have been made in various ways, including the issue of (still largely experimental) special charts such as Admiralty Chart 2649. The chart comparison unit (CCU) first conceived by Mr. R.F. Hansford is an attempt to achieve positive identification by direct visual comparison of the chart with the echoes on the PPI. It seems to offer a method which is particularly suitable to the requirements of pilotage since the comparison is immediate. This paper will consider the general requirements of such a device and describe some solutions which are proposed.

2. THE REQUIREMENTS FOR A CHART-MATCHING DEVICE. The principal, necessary and sufficient condition is that any chart-matching device should provide instantaneous information of the ship's geographical position and of its heading and track, and present this information in a form readily understood by a navigator or pilot.

Scale. It is general in navigation to use the largest scale chart available and it has been stated that a circle of 16 inches diameter will include, on most charts, sufficient targets for reliable position fixing. Experience has shown, however, that this is an under-estimate and a diameter of 24 inches on a large-scale chart is now thought to be necessary; this diameter on a 1 :7 500 chart corresponds to a range of about 1 1/4 miles. On the other hand, when first approaching a coastline the only chart available may be one of 1 : 500 000 scale and the radar may have a maximum range of 30 miles; in this case everything of use is contained within a circle of 9 inches diameter on the chart. It is thus clear that some arrangement is required for continuously varying the relative scales of the PPI and the chart in order to secure matching to the different chart scales; an additional arrangement for varying either the apparent size of the PPI or the apparent scale of the chart is desirable in order to deal with the different-sized « area of interest » on the chart. Instances will occur when the smallest scale of the PPI (at maximum range) will be too great for the normal chart available, but in such cases other and slower methods of obtaining a fix can be accepted.

Convenience. It can be assumed that in fog, in dangerous shoal waters, with other ships in the vicinity, the officer in charge of the ship will have an assistant whose duty it will be to concentrate on the PPI and to maintain the match with the chart, thus freeing the officer of the watch or captain for more important work. The chart-matching device should therefore be capable of being used in a position convenient to the responsible officer, and in such a way that the figures on the chart can be easily read and the ship's position and heading immediately apparent.

Collision Warning. In order to minimize the risk of collision with other vessels their position and tracks should be plotted on the chart so that avoiding action can be taken. A chart-matching device can show the relative movement of the echo and whether it is stationary or moving, and its track can be plotted.

PPI Linearity. The radar PPI for use with any chart-matching device should, of course, give a display which is true to scale at all parts, i.e. the distances measured from the centre to a paint should be proportional to the range of the object causing the echo. This linearity is not always easy to obtain and maintain at all scales, but provided the distortion is not too great it has been found that chart matching is always possible even with a non-linear display. The effect of non-linearity on the accuracy of fix is not easy to assess under all conditions. The amount of non-linearity can be estimated by matching the calibration rings of the PPI with corresponding rings drawn on the chart (at the chart scale), and it is possible to adjust the chart-matching device so that any particular ring is true to scale; the other rings may then be inside or outside their true positions and the positions of echoes near these rings allowed for in matching. It is convenient for chart matching if the scale of the display can be varied continuously but the method of providing scale change in discrete steps is normally adequate because of the scales of charts available. Any scale change provided in the PPI does not, however, absolve the chart-matching device from having variable magnification if charts of all scales are to be usable. To provide special charts for all parts of the world for use with a device is unthinkable.

Method of Use. In order to obtain a correct match the calibration rings of the PPI should be matched with corresponding rings drawn on the chart. Attempts to find the scale by actually matching the display with chart features are tedious and do not give any information on linearity; gross errors in identification are also easily made.

It is naturally easier to match a chart with the PPI if the PPI is stabilized with north upwards, but it is by no means impossible to use a relative display, i.e. with the ship's heading upwards. In some ways the relative display is an advantage since the movement of the chart to maintain the matches is always downwards, but the use of a stabilized display is in most ways simpler.

Importance of the Chart. In all forms of chart matching the PPI is merely a means to an end and is used only to obtain and maintain coincidence with the chart and to show the positions of other moving objects. The chart is itself the best navigational aid and the PPI should be used, therefore, solely to fix the ship's position on the chart and to enable all other ships in the vicinity and their tracks to be plotted on the chart. In this way collision warning is more definite than any attempt to follow an echo on a relative bearing display. In its ultimate form a chart-matching device should carry its own PPI.

3. THE DEVELOPMENT OF CHART-MATCHING DEVICES. Any chart-matching device must of necessity be an instrument by means of which the PPI and the chart can be seen in coincidence. The process of matching consists in superimposing the paints as seen in the PPI on the appropriate features marked on the chart. The identification of an echo as corresponding *beyond doubt* to a charted feature is by no means easy, but it is extremely simple to match the general form and shape of the PPI picture to the chart when these are seen in coincidence. Once such a coincidence has been obtained identification is easy. Fig. 1 shows a typical PPI display photographed in the Solent not far from Cowes, with the ship's heading marker showing that the ship is proceeding in an easterly direction. A number of echoes from objects in the sea are visible and may be other vessels or buoys. Fig. 2 shows the same photograph superimposed on a chart of the area and the

echoes can now all be definitely identified. The ship's position is seen to be just north of West Middle Ground Buoy; Lee Tower and Calshot Castle are identified as well as a number of buoys (some of which are out of their charted positions, possibly due to the set of the tide). Several other echoes, clearly of ships, are also seen.

Chart-matching devices may take a number of forms, which can be divided into three main categories: (Fig. 1 and Fig. 2).

(1) Reflecting devices without magnification.

(2) Optical instruments involving lenses.

(3) Projection devices.

A description of examples of each type will be given.

The Virtual Position Reflectoscope (VPR). This device was developed by the U.S. Navy and could be attached to the face of the PPI of a navigational radar to aid in the recognition of the picture. The operator looked through a semi-reflecting mirror at the face of the PPI and in the mirror saw a virtual image of a special chart placed on a platform below the instrument; the position of the platform was so arranged that the image of the chart was coincident with the face of the PPI.

The charts were specially constructed to suit the scale of the PPI and made about 1 ft. square to fit the instrument. To aid clarity when used in dim lighting only outlines of the coast were shown and prominent features were printed white on black. Originally this instrument was used solely for identifying the coastal echoes but it was soon seen that once chart and PPI were lined up, the central spot showed at a glance the ship's position on the special chart, and that this was of direct navigational assistance if it could be transferred readily to the navigational chart. This problem was first tackled by including a grid on the special chart and drawing a similar grid on the navigational chart. A later form of the VPR made use of copies of the special charts recorded on microfilm with a lens system to provide an enlarged image. Each film was carried in a holder which could be moved by two thumb screws which drove two drum counters, from which grid references could be read directly and plotted on the navigational chart.

The labour involved in preparing the special charts or microfilms was large, but this was of no particular consequence as the instrument was intended for use in special naval operations where a large amount of pre-planning was in any case involved. For all other purposes the elaboration of the system and the high cost of the precision optical equipment would have been prohibitive and, so far as is known, the system has never been further developed.

The Reflectoscope. At the same time that the above work was proceeding in the United States a system of producing « predictions » of the expected appearance of PPI pictures was being developed in Britain. These predictions were first held alongside the PPI purely as an aid to recognition when approaching an enemy coastline; in later operations they had an intended track marked on them and were produced as transparencies which could be held over the face of the

PPI and used directly for navigation. The accuracy was, however, very poor owing to parallax errors. When it was decided to use this method of navigation on a large scale it was clear that the accuracy must be improved and consequently a simple form of chart-matching device, known as a « reflectoscope », was developed. This was based on the earlier United States VPR and no particular advantages were claimed for it, other than that it was simplified to the point where very rapid production could be arranged. It consisted of a single piece of semi-reflecting mirror in front of the PPI at 45°, with a glass sheet above, on which the transparent prediction could be rested, and a light source. These early experiments showed that the chart-matching system could be used very successfully for pilotage in fog. Its chief disadvantage was that, like its U.S. predecessor, it could only be used for specific operations where special forms of charts could be prepared beforehand.

The First Chart Comparison Unit. The previous work suggested that a considerable step forward would be made if it was possible to view the PPI in coincidence with a standard navigational chart. As well as obviating the need for pre-planning and producing special charts this would have the advantage of allowing all fixing and plotting to be done directly on the navigational chart itself. Fig. 3 shows the principles of the earliest device to work on this system. It was first described by Hansford and named by him the « chart comparison unit ». This name has now been adopted generally for chart-matching devices and, following the modern custom, has been reduced to the initials CCU.

The principal disadvantages of these simple forms of CCU are the scale limitation and the lack of light. The area of chart which can be matched cannot be greater than that of the face of the PPI, and under most practical conditions this means that the scale of the chart used is small. In order to see the reflection of the PPI in the semi-reflecting plate there must be very little light on the chart; the instrument must in fact be used in very subdued light which, of course, makes it extremely difficult to see the chart. Many other forms of beam splitting devices can be used, some of which are shown in Fig. 4. The scale limitation can be overcome to some extent by using a lens to magnify the PPI so that it can be matched with a larger area of chart.

The A.R.L. Chart Comparison Unit. In all instruments of the simple type, scale adjustment must necessarily be done on the PPI and thus it is necessary to provide a PPI having a continually variable scale adjustment, combined with steps if necessary, to meet all the possible chart scales. Optical instrumental methods of varying the scale appear up to the present to offer the most promising practical solution of the problem, and instruments of this type are being developed for naval use by the Admiralty Research Laboratory.

In optical chart comparison units the principle which was finally adopted by A.R.L. after many trials at sea is to view simultaneously the face of the PPI and the chart using telescopic optical systems with an eye-piece into which the observer looks, and with some means of screening all external light from the face of the PPI. The PPI may be seen enlarged or in its natural size but the area of chart seen can be varied over a wide range of magnification by means of a variable focus optical system. Thus the scale of the PPI can be adjusted electronically to that most suitable for the particular distribution of land objects and the optical variable focus system enables a chart of a suitable large scale to be seen at an apparent scale equal to that of the PPI. To enable the instrument to be used in full daylight or in a brightly lit room, or alternatively in subdued or red lighting, a variable density filter is incorporated in the system so that the balance between the light from the PPI and that from the chart can be adjusted to enable both to be easily visible in coincidence. The variable density filter also enables the observer to concentrate either entirely on the PPI or on the chart. External light is excluded from the PPI by using a shield between the instrument and the PPI or the latter can be placed in a light tight box which serves also to support the CCU at the correct height above the chart table. Fig. 5 shows a prototype A.R.L. unit in use on a ship's bridge.

A projector lamp is fitted to the instrument and projects a spot of light on to the chart with a cross or a circle to indicate on the chart the ship's position and a rotatable arrow to indicate the ship's heading. Other refinements consist of a disk on which any particular scale setting can be marked for future reference, locking devices to prevent accidental movement of the scale-change knob and a means of focusing to suit the eyesight of the observer and to bring the chart and the PPI into focus in the same plane to avoid parallax.

The instrument may be used with any size of tube and the PPI may be to the left or to the right, above or below, straight in front or at any angle, except in the simpler form of instrument shown in Fig. 6 which is intended to clip on to a PPI straight in front of the observer.

In a later form of the instrument a remote PPI is incorporated in the CCU itself, so that the instrument can be fitted over a chart table wherever convenient and may be mounted on rails to allow it to be moved over the chart table. Fig. 7 shows the general appearance of the combined instrument and it will be seen that the PPI controls are in a convenient position for adjustment, being fitted to the face of the PPI chassis, which can be removed for servicing.

Internally the instruments consist of a telescopic system through which the PPI is seen slightly magnified and a second telescopic system, incorporating moving parts, through which the chart is seen under a variable magnification or reduction over a range of three to one. The two telescopic systems have a common eye piece, the two beams of light being brought together by prisms to a beam-splitting block which uses an interference filter layer so that there is very little loss of light. In principle, interference filters reflect and transmit light of complementary colours and there is theoretically no light lost by absorption in the layer as there is in metallic semi-reflecting surfaces. Actually the light lost is very small and the bands of complementary colours transmitted and reflected are so arranged that both beams appear to be neutral in tint or very slightly coloured.

The variable density filter is inserted in the telescope which views the chart and is arranged so that any desired intensity of light from zero to the maximum is transmitted to the eye. The ship's position and heading projcctor is built into the instrument and the direction of the heading arrow is adjusted by means of a knob engraved in bearings. The smaller instrument (Fig. 6) is intended for use in small ships where space is restricted and in this instrument there is no telescope for viewing the PPI, which is thus seen at its natural size ; otherwise the instruments are identical.

Fig. 1 — Photograph of a PPI display in the Solent.

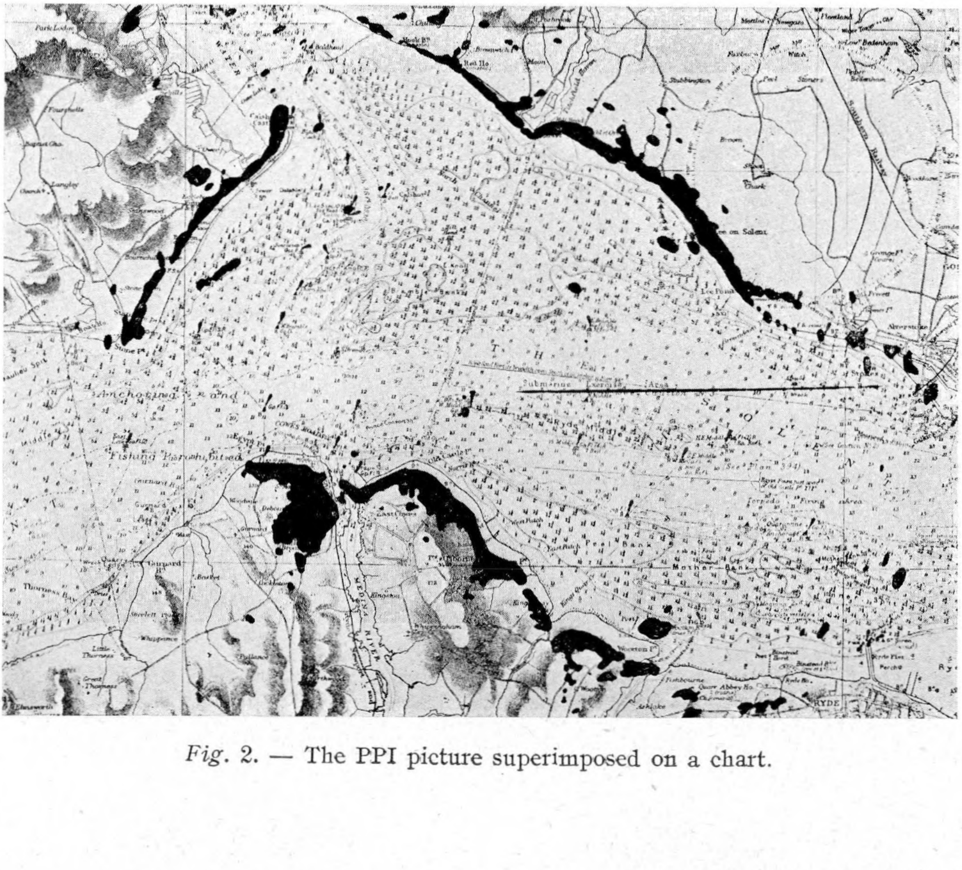

Fig. 2. — The PPI picture superimposed on a chart.

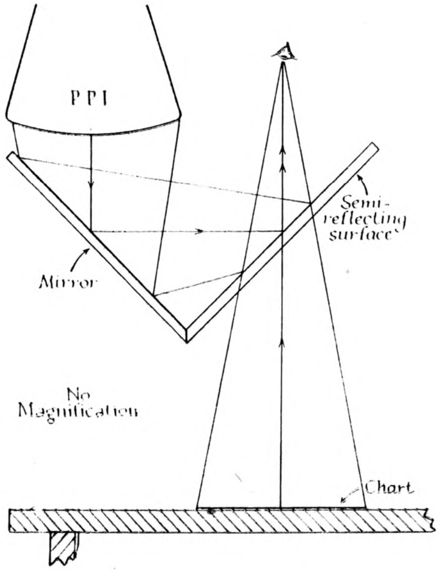

Fig. 3. — The principle of the first CCU.

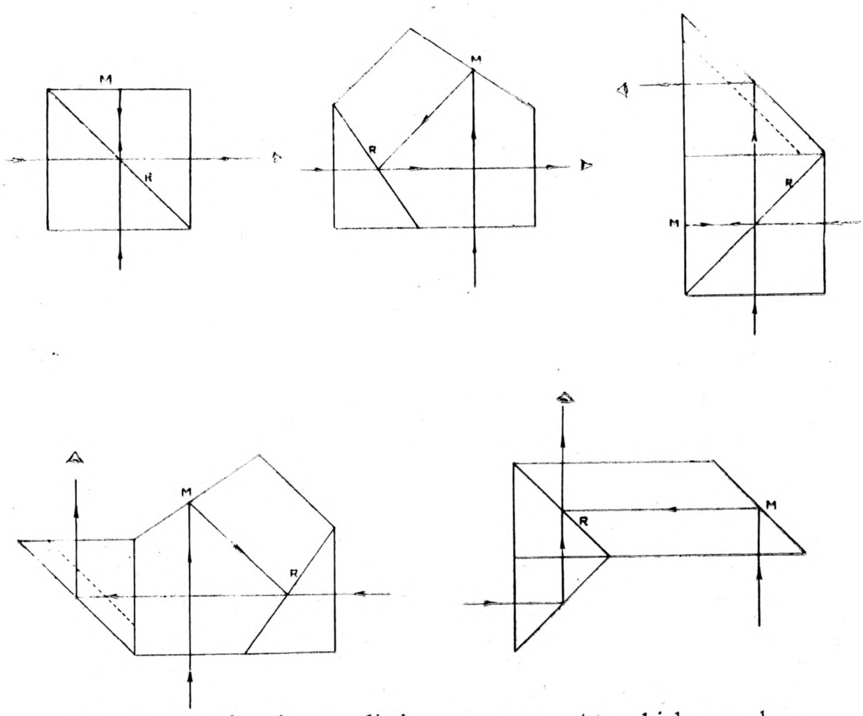

Fig. 4. — Five beam-splitting arrangements, which can be used for chart comparison with or without lenses.

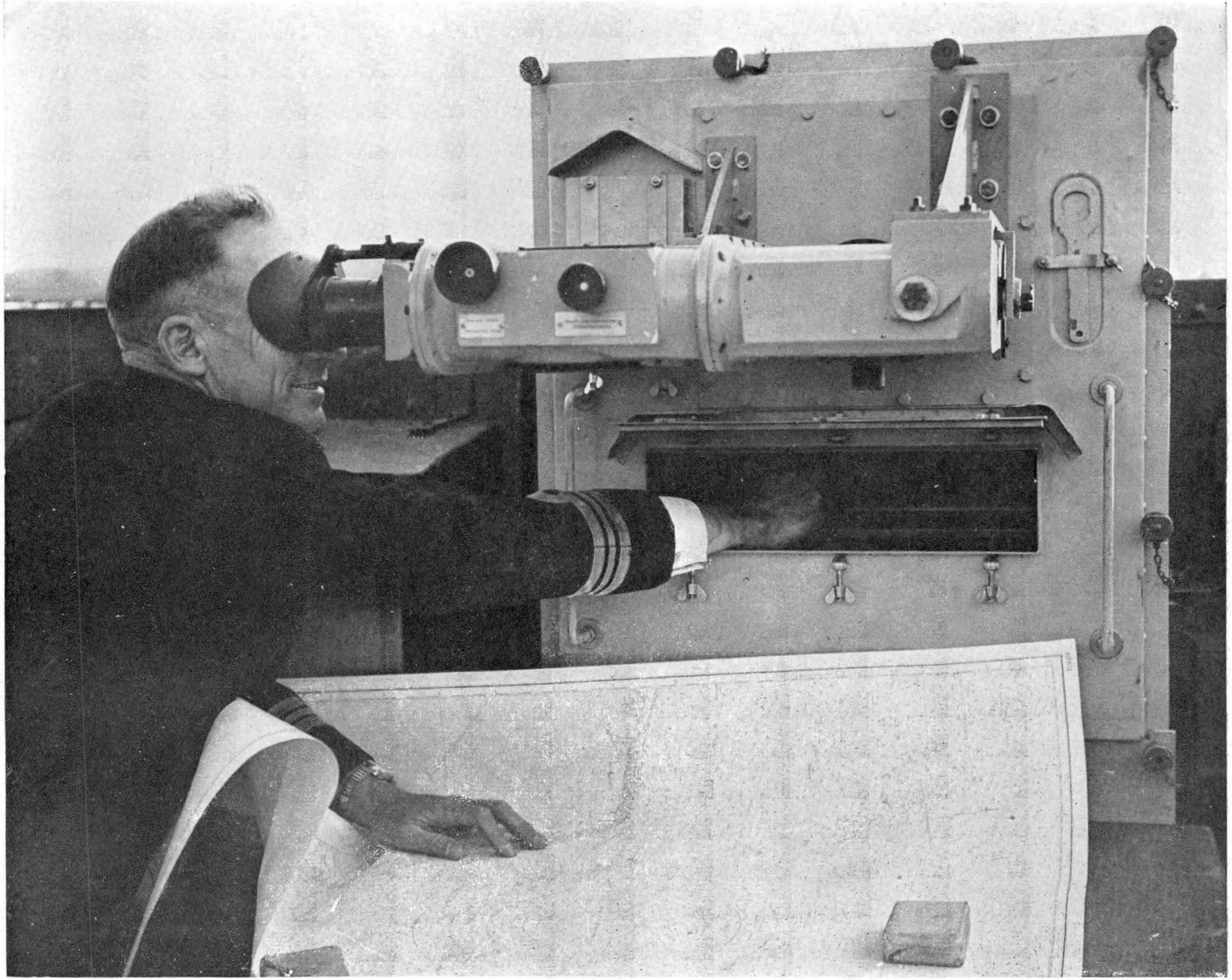

Fig. 5. — An A.R.L. chart comparison unit (Type C.Y.1) in use on the bridge of H.M.S. *Sharpshooter.*

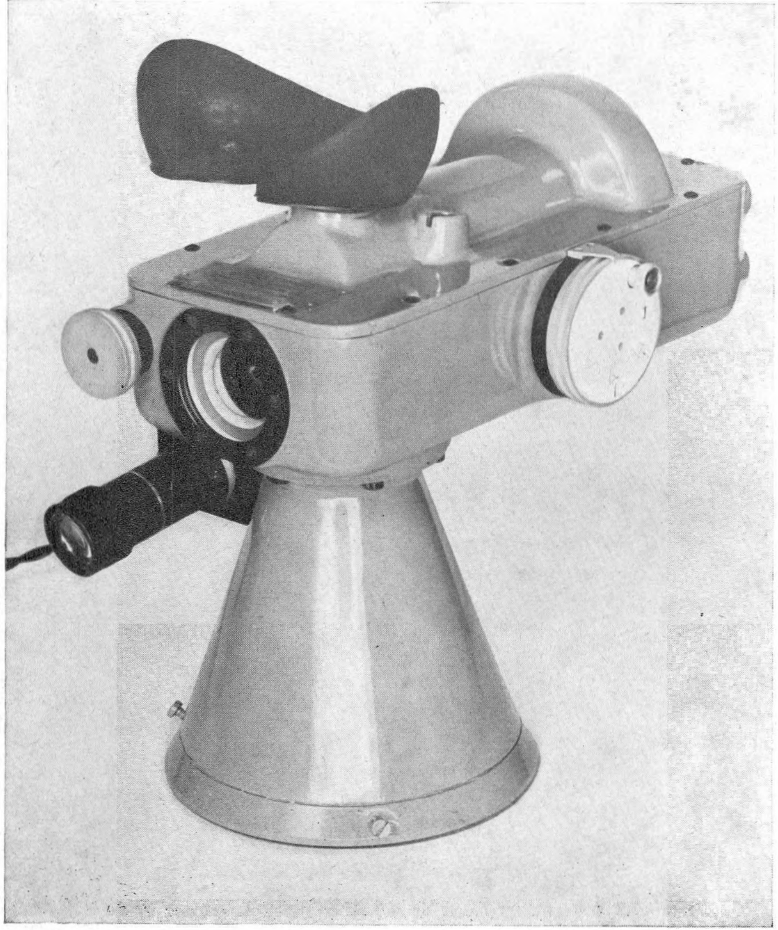

Fig. 6. — A small CCU for fitting on to an existing PPI in small ships.

Fig. 7. — The combined PPI and CCU.

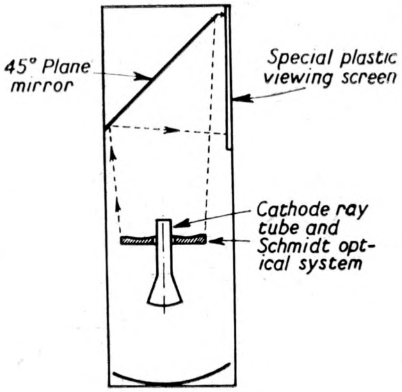

Fig. 8. — Possible projection systems using the principle of the Schmidt camera and transparent charts.

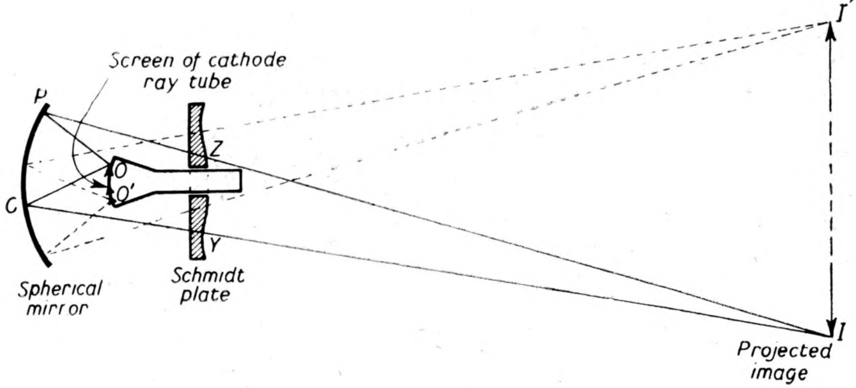

Fig. 9. — Another Schmidt projection system for opaque charts.

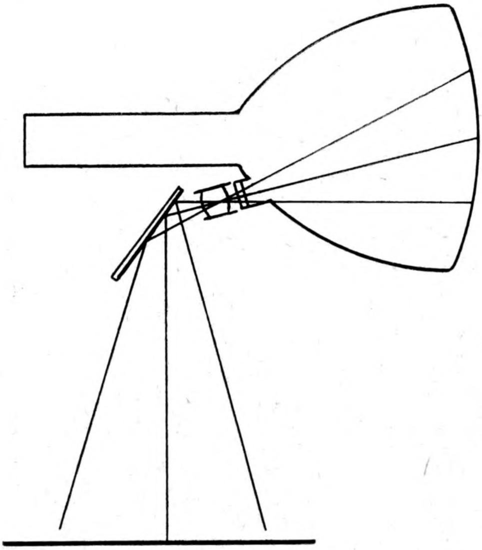

Fig. 10. — The spherical projection tube suggested by Hansford.

Projection Methods. Among projection devices there have been more suggestions than successful applications. Fig. 8 shows a possible projection system using the Schmidt principle, which has been adopted successfully for television receivers. Provided a tube of small dimensions and very high brilliancy could be used in the PPI there is no reason why a system of this kind could not be used for chart matching. In the form shown it would require transparent charts.

Another possibility is shown in Fig. 9 in which the PPI is projected on to a chart lying on a table. Scale variation can be accomplished on the tube itself, but the general level of illumination on the chart would have to be very low and the chart would not be visible for normal navigational use.

Many other optical projection systems could be evolved, but up to the present time no tube of sufficient brilliance has been developed, and even if a satisfactory tube were available experience with projection methods has shown that the use of a darkened room makes it very difficult to see detail on the navigational chart.

Another suggestion due to Hansford is shown in Fig. 10 in which an optical flat window could be built into a cathode ray tube and used to project, with the aid of a lens and mirror system, an image of the navigational chart on to the back face of the PPI where it would be seen with the PPI picture. There may be some future in this idea, but so far no tube of this type is available, nor does it seem probable that one will be developed ; and it is difficult to foresee whether the projected image could be made sufficiently bright while still maintaining the PPI picture.

Messrs. Kelvin & Hughes have developed an experimental projection system in which the PPI is photographed and the film rapidly processed and projected on to a screen. This method allows of much more light being used for projection, but the chart would still be difficult to see and it is doubtful if the apparatus would lend itself to shipboard use because of its complexity. The system has, however, other applications and is worthy of consideration where very large scales are required ; for example in shore-based harbour radar systems. The map or chart can be permanently engraved on a plate and projected on to the screen with the PPI picture.

4. EXPERIENCES WITH THE CCU. All the instruments, though not suggestions, described have been given trials at sea under actual pilotage conditions, and it would take much space to describe all the adventures and experiences. A few examples must suffice and will be confined to the use of the optical instrumental CCU which the Admiralty Research Laboratories have developed. The development of these instruments has taken some years and the work has been guided by actual experiment and trials at sea. The opinions of many people have been sought, almost every suggestion has been tried and the decision to concentrate on the optical CCU was only arrived at after a very full and impartial assessment of all other methods had been made.

One instrument was fitted to a remote PPI on the bridge of H.M.S. *Sharpshooter* (Lt.-Cdr. Berncastle) at the request of the Hydrographer of the Navy, and a long series of tests were carried out in the North Sea between Grimsby and

London. Owing to some difficulty with the type of PPI the largest scale charts could not be used, but much work was done with charts on a scale of 1 :50,000. Working in the Thames Estuary presented no difficulty whatever as there were many land objects, forts and buoys. It was found that it was usually possible to fix the ship's position with about the same accuracy as with compass bearings. Off Yarmouth and Cromer the CCU showed on one occasion that the Cromer lightvessel was not in its charted position, and this fact was verified by bearings. The Norfolk and Suffolk coastline can hardly be described as ideal for radar position fixing as it is low lying on the whole, convex towards the sea and there are very few sea markers. Nevertheless the CCU gave excellent results as the detection of the error in the position of the lightvessel confirms. On another occasion a large echo was seen to emanate from an object which was apparently stationary on a sandbank, and on investigation this proved to be a large cargo vessel aground. The first report of this vessel in its unusual position was received with considerable scepticism and its later confirmation did much to convince the ship's officers of the value of CCU.

The ship was successfully tracked through the fishing fleet at anchor off Grimbsy. Under fog conditions off Yarmouth the captain had by this time so much confidence in the CCU that he continued his course normally towards Lowestoft and made a successful passage with only its aid.

Another instrument was fitted on the bridge of H.M.S. *Starling* (Cdr. Paine) when she was in use as a training ship for navigating officers. During these trials innumerable incidents occurred which proved the qualities of the CCU. A chart of natural scale 1 :20,000 was used for most of the work but for the entry into Porstmouth harbour the largest scale chart of that harbour was successfully used. On one occasion a pupil nearly succeeded in running the ship aground, and would have done so had it not been that the CCU was being used independently at the time and a warning was passed to the captain in time to avert the grounding of the ship. On another occasion the ship was in some trouble with the Yarmouth-Lymington ferry steamer and the CCU gave a most graphic and convincing picture of the tracks of the two vessels during their evolutions to avoid collision. The entry into Portsmouth harbour was most spectacular and showed the value of the instrument at a very large scale, the track of the ship being plotted almost to the quayside on the NW. wall.

An instrument was also fitted in a small motor boat, on an unstabilized PPI of very small size and poor performance. Successful work was carried out under very difficult conditions in and around Plymouth harbour but the CCU was shown to possess the necessary qualities for successful pilotage. The continual rotation of the chart as the motor boat changed course did not present any great difficulty, but it would have been much preferred if the PPI had been stabilized.

5. ACKNOWLEDGEMENTS. The permission of the Admiralty to publish this paper is gratefully acknowledged ; the views expressed, however, are not necessarily official ones.

ORDINARY MEETING

Mr. J. Home Dickson's paper was presented at an Ordinary Meeting of the Institute held at the Royal Geographical Society on the 16 May 1952, the President, Rear Admiral A. Day, in the chair.

DISCUSSION

THE CHAIRMAN : We have listened to a most fascinating story of development and been disarmingly led into some of the inner secrets and difficulties encountered.

I personally am to be found among those who believe that the chart-matching solution of the radar fixing problem starts with the right basic principle. I may be biased as a chart producer, although it is not so long ago that I was a chart and radar user. I now appreciate the number of man-hours that have to go into the production of a new chart and I am all the more content when a new tool, such as radar, is shown to require little alteration to the chart styles suitable for the visual navigator.

Lieut.-Commander M.J.L. Blake (H.M.S. *Dryard*): I assume the latest optical CCU with a cathode ray tube incorporated is normally fixed over the chart table and the chart moved about underneath it. It will be necessary to have a very large chart table to prevent the ship's position going off the edge. Has M. Home Dickson considered the CCU being moved about over the chart as opposed to the chart being moved about under it ? It looks as though it might be possible and would be an advantage to have the CCU mounted on such a form of rail.

MR. HOME DICKSON : The bigger the chart table, the easier it is to work. In fact, however, we worked in H.M.S. *Starling* on a table less than 2 ft. by 1 ft.6 in., and the chart had to overlap in various directions ; this was awkward, but we managed. In H.M.S. *Sharpshooter* we had a reasonable sized table, 4 ft.6 in. or 5 ft. between the ends but even so we had to fold the chart up; for instance when we were in the south-east corner the whole of the north-west corner had to be folded out of the way. A large chart table is a help, but it is not essential.

There is the possibility of an automatically moving chart table now being developed. The ship's course is set on a dial and by turning a handle the chart moves at a speed determined by rotation of a handle. Alternatively the table may be connected to the ship's automatic log and the chart driven automatically at the correct speed. Such a table, however, would take up a fairly large space.

As regards the self-contained CCU-PPI instrument we have thought of the possibility of mounting it on a gantry worked from above, so that it can be moved in every direction over the chart table.

MR. A.L.P. MILWRIGHT (R. N. Scientific Service) : We have heard of investigations into the use of projection devices for chart comparison and of the difficulty in varying the magnification to match a wide variety of charts. Has Mr. Home Dickson considered using a fixed optical magnification with a variable natural scale of PPI ? The variation of the radar scale can be accomplished quite easily.

MR. HOME DICKSON : I think I mentioned that under extreme conditions when working, say, in a harbour, the amount of chart one wants to see is very large ; a large-scale chart must be used and it is necessary to see a large area of it because of its scale. If an attempt is made to enlarge the PPI picture electrically to the same scale, the land will disappear off the edge of the tube. It is possible to arrange the optical magnifications so that the user will always look at a 12-in. PPI, say, in comparison with a 27-in. diameter of chart; i.e. there is a fixed magnification or minification of chart against a fixed magnification of the PPI and the user alters the scale electronically over the range required to suit different charts. This is all right so long as large-scale charts are being used. As soon as it is necessary to use a small-scale chart it becomes necessary to diminish the scale of the PPI enormously, so that there is far too much space all round the useful area; a very small area in the middle of the PPI is being used and the rest of the picture is useless because of having reduced the scale to suit the small-scale chart. We found it necessary to see a 9-in. diameter circle on the chart at scales of 1 : 500 000 or 1 : 250 000 but a very much larger area of chart at scales of 1 : 7 500 or 1 : 5 000. It seems necessary to alter optically the amount of chart visible. This question has been raised by many people, for there is no doubt that it would be very easy to alter the scale of the PPI electrically.

MR. L.S. LE PAGE (Ministry of Transport) : On most radar indicator units the PPI slopes backwards, I would like to ask whether Mr. Home Dickson intends to correct for this slope optically or whether with a vertical PPI a separate remote unit is required.

MR. HOME DICKSON : There is an optical method of getting round any corner, but it is usually more convenient to tilt the PPI into a vertical position. In cases where the PPI has been permanently installed at an angle and cannot be made vertical, the larger instrument will enable one to do what is necessary. The best solution is, of course, the instrument with the self-contained PPI.

Captain HUGH TOPLEY (Ministry of Transport) : Is there much difficulty in using the instrument without the gyro-stabilized PPI, or would it normally be necessary to fit a gyro stabilizer before you install a CCU ?

MR. HOME DICKSON : Using the CCU with the unstabilized PPI is more difficult than with the stabilized, but I found in an M.T.B. that after about an hour's practice I could follow the display round without trouble and I was able to obtain a fix whenever required. The second point is purely economic. Having fitted a CCU you might decide to fit a stabilizer because it simplifies the operation but there is no necessity to do so.

MR. E.J. DOHERTY (Sir John Cass College) : We have heard very little about the projection display system which Phillips are using. With a small tube surely very high definition and a considerable increase in light can be achieved. A unit such as that described working on to a matt screen on a table would be quite suitable for a relative plot and would be very helpful. Has that been thought of ?

MR. HOME DICKSON : We have tried most of these suggestions. It was impossible to obtain a tube of sufficient brilliance for actual projection but mock-up tubes were made with a light behind a transparency. In using a chart it is imperative to be able to see the features on the chart including the soundings ; this means some light on the chart ; to see the projected image, however, the chart must be in relative darkness. Another difficulty is that the light echo must fall on a dark chart feature when a match is obtained and there is difficulty in seeing the echo on the dark ground.

MR. DOHERTY : If we are going to think in terms of a plotting unit as such, then a CCU is very little use for relative plotting. I would rather see some form of projection system with which one could actually plot the echoes relatively, and for this one would surely need a screen and not a chart? If the screen were grey it should be possible to produce sufficient light on it from a tube of 2 1/2 in. diameter, working on about 14 kV., which would give a very brilliant picture indeed.

MR. R.F. HANSFORD : It is relevant to say, briefly, that a projection display of that type is the ambition of every radar engineer, and has been for the last ten years. Unfortunately no one knows how to produce such a display in an economical form. The projection tubes of the type which Mr. Doherty has in mind are the television variety and these do not include an afterglow screen. Experiments with storage type tubes and other techniques are being carried out but there is little hope of these being used in the near future for ordinary marine radar.

MR. W. STRUSZYNSKI (R.N. Scientific Service) : Would it be of any advantage to use two separate optical systems enabling one eye to observe the chart and the other eye to observe the PPI?

MR. HOME DICKSON : We have experimented with this idea but gave it up for several reasons. The eyes can only converge, they cannot diverge, and they can only look up or down together. If an attempt is made to match two objects using one eye to see each there is always considerable eyestrain unless the two objects are correctly placed. If the two objects are slightly twisted in relation to each other, too far apart or one slightly above the other, it may be possible to make them appear coincident because one has considerable control over the eye muscles, but in a very short time one would have a headache.

Lieut.-Commander F.M. BERNCASTLE (Admiralty Hydrographic Department) : I was fortunate enough to be in *Sharpshooter* when Mr. Home Dickson came to do some of his earlier trials. I was sceptical of the value of the CCU at first, but later, when he had left, we went up the Humber and on to Killingholme jetty in thick fog and I found I was able to plot my whole way up, keeping off the shoals and between the banks which I had never seen in daylight. I was quite happy going up on the chart using the CCU and that convinced me of its value. I feel that others will be convinced and find the CCU indispensable once they have had an opportunity to use it.

It was convenient for the navigator to look through the instrument, keeping a continuous plot of the position of the ship, and for myself, in command, to keep an eye on the various ships, mostly at anchor, which appeared out of the fog. It would have been helpful, however, if I could have occasionally looked through another eyepiece and seen the actual match that the navigator was viewing.

MR. HOME DICKSON : There is no real reason why another eyepiece could not be added on the side of the instrument, so that another operator, or the captain, could look in.

MR. M.H. EASY (Decca) : I should like to know whether in fact the difficulties of using a chart comparison unit with a relative display have not been over-emphasized. The example given in the paper referred to an M.T.B. but it would be interesting to know whether, during his trials in *Sharpshooter*, for instance, Mr. Home Dickson tried the CCU with the display unstabilized.

MR. HOME DICKSON : No, we always had it stabilized in *Sharpshooter*. I agree, therefore, that the question of stabilization has been over-emphasized, since it is comparatively easy to use the instrument with a relative PPI.

MR. MILWRIGHT : The mariner who prefers an unstabilized PPI generally prefers a heading-upward display. The use of CCU under these circumstances would involve the operator standing on his head to read the lettering on the chart when steering south.

MR. HOME DICKSON : The only way to overcome this difficulty would be to have two charts, one below the CCU and the other on the chart table the right way up.

Captain A.R.P. SHAW (Retired Master Mariner) : The captain of a merchant ship is responsible for the navigation of his ship as well as for avoiding collision. This seems to imply that another officer will be needed to manipulate the CCU.

MR. HOME DICKSON : If the ship is in any danger, such as in a fog, there will, I assume, be more than one officer on the bridge. The captain can then give his undivided attention to the navigation of the ship and look into the instrument from time to time to convince himself that all is well.