RADAR — AN AID TO PILOTING

Prepared by the U.S. Naval Hydrographic Office.

Among the most important of the recent developments affecting the techniques of navigation and piloting, is radar. As the name indicates (Radio Detection and Ranging), it was developed for the purpose of detection and determination of the location of ships, aircraft, and land masses within the range of the equipment. It promises to fill a long standing need of the merchant marine for an anti-collision and piloting device that may be used during darkness and low visibility.

The radar equipment is essentially an instrument for measuring the distance, from the transmitter, of an object which will reflect electro-magnetic energy of radio frequencies. This is dependent on three fundamental characteristics of radio waves ; they travel at a constant velocity on a linear path in a homogenous medium ; they may be directed in a definite pattern ; and they (high frequency waves) are reflected by objects or mediums of sufficient density.

Although there are several systems which have been advanced for radio detection, the one commonly accepted today is the pulse modulation system. This involves the emission of pulses of high frequency energy in a narrow ellipsoidal beam. The objects in the path of the pulses reflect an infinitesimal portion of the energy back to the antenna. This small portion is amplified and modified so that by the utilization of the principles of the oscilloscope, the time interval (thereby the distance) is measured and a visually intelligible presentation is made.

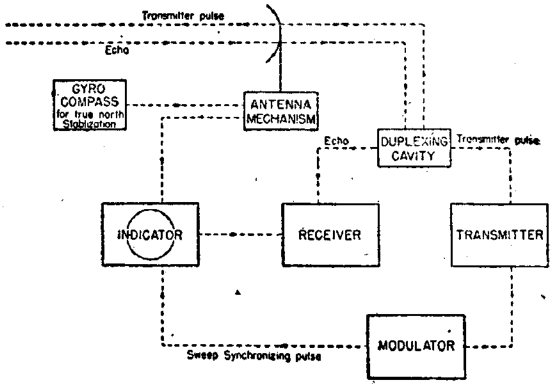

FIG. 1

As shown by figure 1, the radar equipment consists of five basic units. Although these units may be together or separate, depending on the design, they are to be found in all radar sets.

The high frequency energy necessary is generated by an oscillator, usually a magnetron, in the transmitter. The release of this energy in pulses, of one micro-second or less in duration, is controlled by the modulator. The pulse rate frequency may vary from 800 to 2500 per second. After the emission of each pulse the transmitter is silent in order that the echoes may be received.

The generated energy is conveyed to the antenna by a hollow metal waveguide and then beamed in the desired direction by a carefully designed parabolic reflector. The antenna assembly consists of the radiating unit, the reflector, and the rotating machinery. It may be controlled by the ship's gyro compass in order that the indicator may present true instead of relative bearing information.

Since the same antenna is used for both transmission and reception, the " duplexing cavity " is necessary so that the transmitter power output may be prevented from entering the receiver.

The receiver, which is of the superheterodyne type, lowers the frequency of the incoming signals to one more convenient. This modified signal is then fed into the indicator unit which utilizes a cathode ray tube for the presentation of the information.

The deflection of the electron stream, or the " sweep ", from the center to the periphery or from one side to the other is commenced synchronously with the emission of each transmitted pulse. If the reflected and modified signal from the receiver is impressed on the cathode ray (CR) tube so as to cause a momentary intensification of the screen image at some point during the sweep, the distance from the starting point of the sweep will be proportional to the distance of the reflecting object.

Although the desired information may be variously presented on the screen of the CR tube, the two most common presentations are called the " A-scope " (1) and the " PPI-scope " (2). An A-scope is usually the more accurate in the determination of range. However it has the disadvantage of failing to indicate the shape or bearing of the reflecting objects as readily as the PPI-scope. This type of presentation (*fig.* 2c) is not as valuable to the mariner as the PPI-scope presentation (*fig.* 2d). The PPI-scope provides a map-like indication of the ships, or any sizeable reflecting object in the vicinity of the transmitter. This type of presentation has the advantage of giving an integrated summary that may be interpreted at a glance by personnel with the minimum of training. No plotting of signal is required in order to determine the relative position of the various objects. Also, the differentiation of ships and land masses is simpler.

This " radar picture " of the nearby objects and terrain differs from the true configuration for several reasons. The four most important sources of

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(1) Scope : a contraction of oscilloscope.

(2) PPI : plane position indicator.

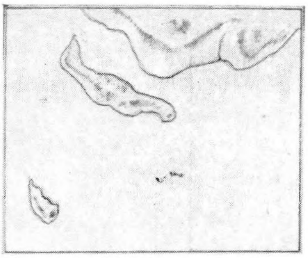

FIG. 2 *a*
Conventional map presentation

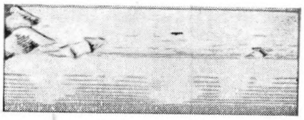

FIG. 2 *b*
Pictorial view

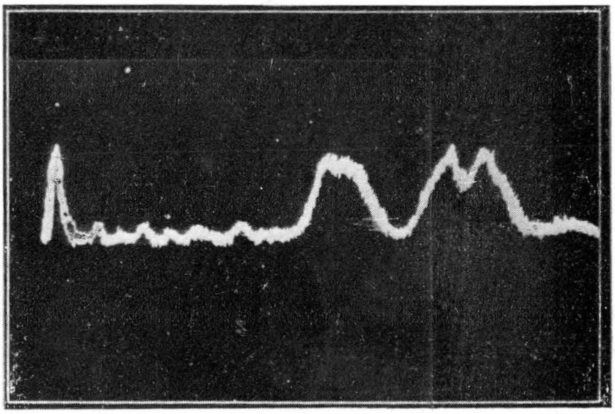

FIG. 2 *c*
A-scope, bearing approx. 010° *T*

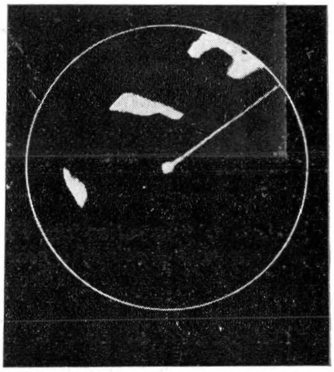

FIG. 2 *d*
PPI-scope presentation corresponding to fig. 2 a

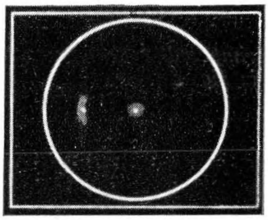

FIG. 3
A characteristic buoy signal return

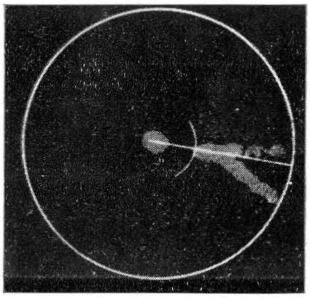

FIG. 6 *a*
Range and bearing fix
(See fig. 11 *c*)

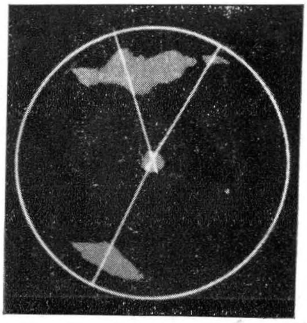

FIG. 6 *b*
Three bearing fix

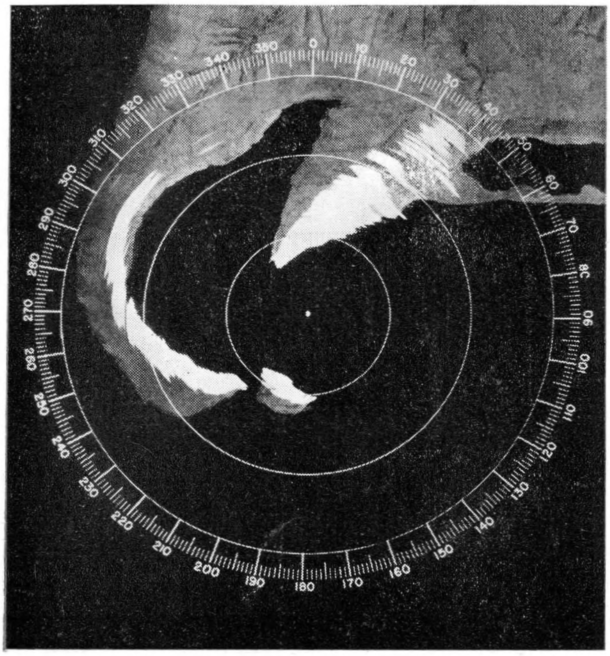

FIG. 5
In this illustration the PPI presentation is superimposed on a photograph of a relief model of the island in fig. 4.
(See also fig. 9)

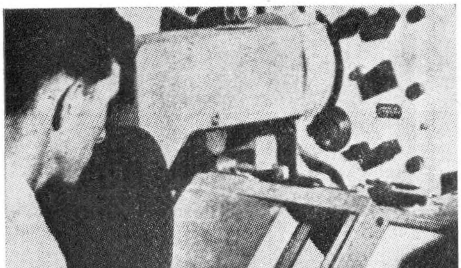

FIG. 7 *b*.
VPR mounted on Radar Indicator

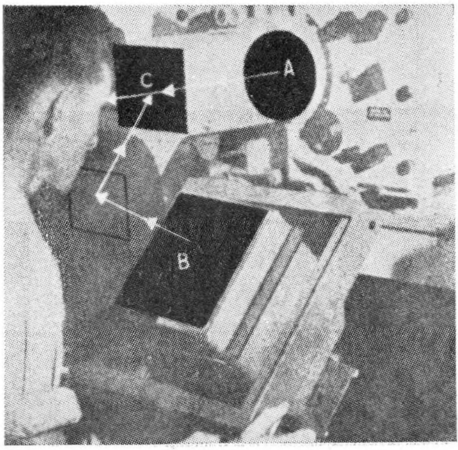

FIG. 7 *c*
Diagramatic view of VPR

differences are : *a*) The effect of the width of the transmitted energy pattern ; *b*) The time duration of the transmitted pulse ; *c*) The " shadow " areas, and *d*) The strength of the reflected signal.

The horizontal width of the transmitted energy pattern, depending primarily on antenna design and frequency, is usually from 5° to 15°. A single point will reflect the energy during the entire width of the beam as it sweeps by. Consequently, an object such as a buoy or a lighthouse will be indicated on the scope as an arc with the angular width the same as the beam width (or slightly less). A shoreline will have a corresponding distortion as each point on the shore appears as an arc on the scope (*fig.* 5 and *fig.* 9).

In addition to the angular distortion, there is a radial distortion caused by the duration of the transmitted pulse. If, for example, the pulse duration is one micro-second, then all scope signals would be increased radially in width 983 ft. (*fig.* 3).

The behavior of the beam of pulses, being at a high radio frequency, is similar in many ways to a beam of light. The most important aspect affecting the appearance of the signals presented on the scope is the existence of " shadow areas ". That is, land, ships, etc., behind higher ridges, hills, and other objects will reflect no energy and consequently will not appear on the scope. Similarly, objects that are below the horizon will not be detected except under unusual atmospheric conditions.

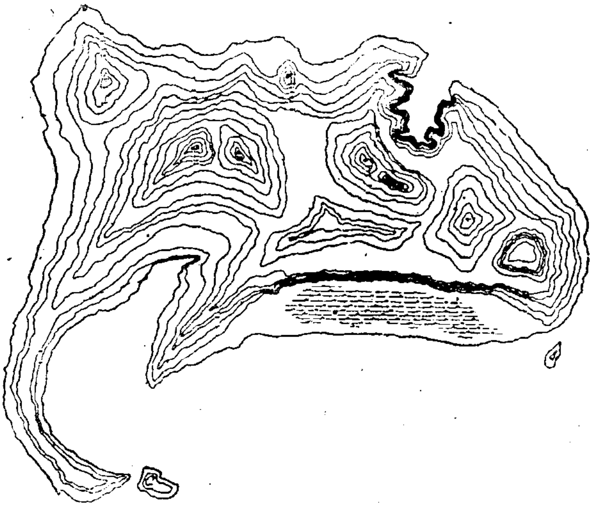

FIG. 4
Contour Map of a hypothetical Island

The fourth factor affecting the presentation as contrasted with the true form is the varying reflecting characteristics of the various terrain surfaces. Cliffs, steep hillsides, or large metal structures possess a greater reflecting power than low flat land, sand spits, mud flats, and marshes. The latter will frequently provide no indication of their existence, even at comparatively short ranges of two or three miles, while mountain peaks may occasionally be detected at distances of 75 or more miles, depending upon their elevation, the height of the radar antenna, and other factors. Water is an excellent reflector. Because of this great reflectivity the radio waves are reflected *away* from the transmitter consequently the areas representing water appear as dark areas on the scope.

Figures 4 and 5 illustrate the variance of the radar PPI presentation as compared with a conventional contour map and a relief model of an island.

A fifth factor is rather unpredictable. The propagation of radio waves is affected materially by the atmospheric conditions of humidity and temperature. This will cause the effective range of the equipment to vary from day to day. Refraction of radio waves in the lower atmosphere occurs in a manner similar to light. Due to the change of index of refraction with height the actual path of the radio waves may be curved downward so that effective ranges are greater than line-of-sight distances. This change of index of refraction, or " super-refraction " as it is sometimes called, may be produced by a pronounced increase in temperature with height (temperature inversion), or by a pronounced decrease of moisture with height (moisture lapse), or a combination of the two. The conditions often found in the central mediterranean are conductive to this phenomena.

Piloting.

The use of radar as an aid to piloting is, of course, limited to the range of the equipment. The determination of position may be accomplished similarly to the methods used in conventional piloting. The plotting of two or more bearings, two ranges, or a range and a bearing will often suffice to provide a sufficiently accurate fix. However, since the bearings or ranges are not taken visually but from the signals on the scope, it is occasionally difficult to determine which scope signal corresponds to the desired topographic feature. Straight shore lines without distinctive features, for an example often fail to provide identifiable traces for range and bearing observations. The ability to interpret the scope and to make accurate measure-

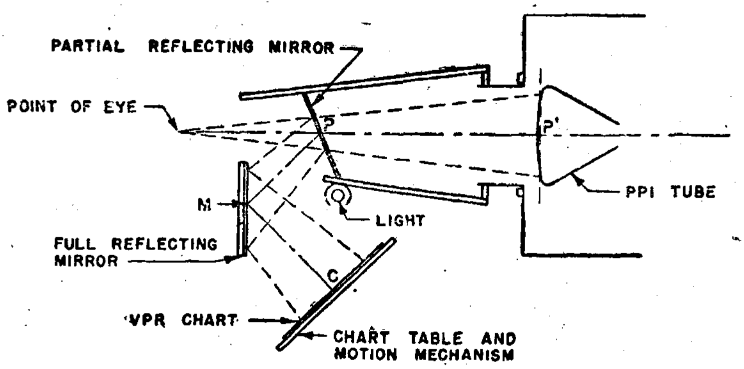

FIG. 7 *a*

Optical principles of VPR

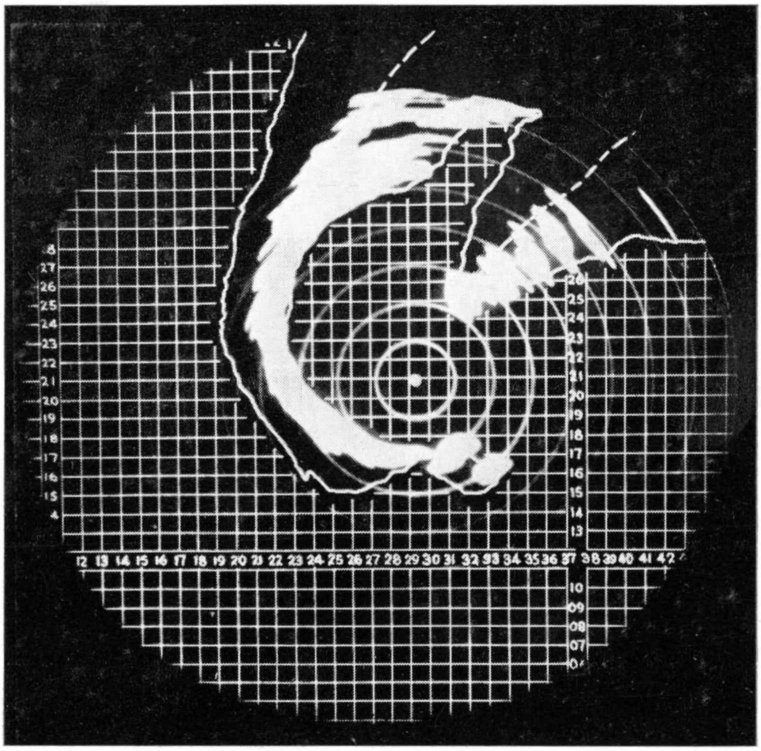

FIG. 9
Photograph illustrating the "matching" of the Scope signals with the Radar Chart

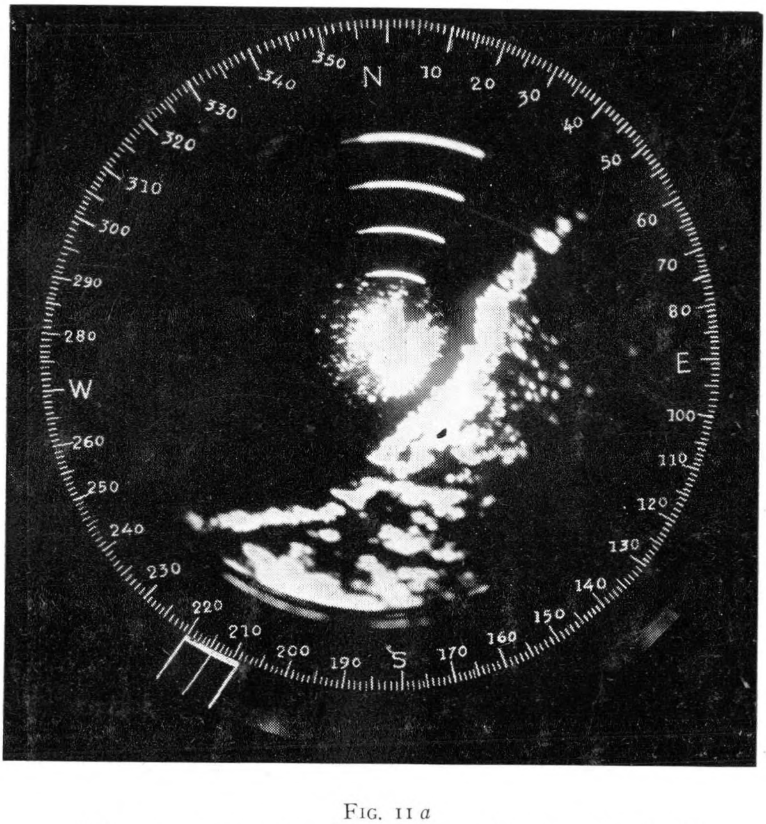

FIG. 11 *a*
PPI-scope photograph. — Position : 21° 38',7 N., 158° 07',3 W.

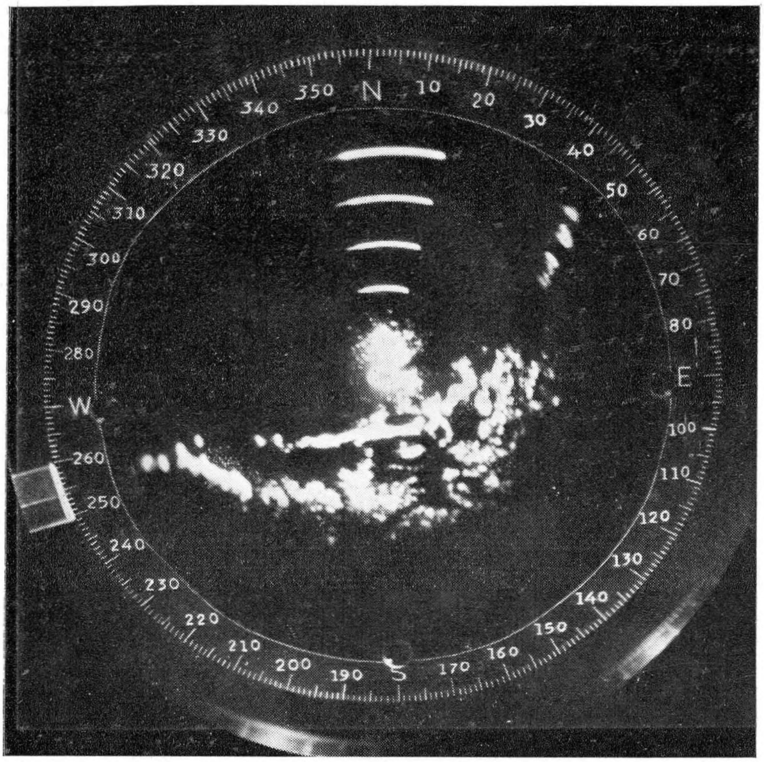

FIG. 11 *b*
PPI-scope photograph. — Position : 21° 36',3 *N.*, 158° 08',2 *W.*

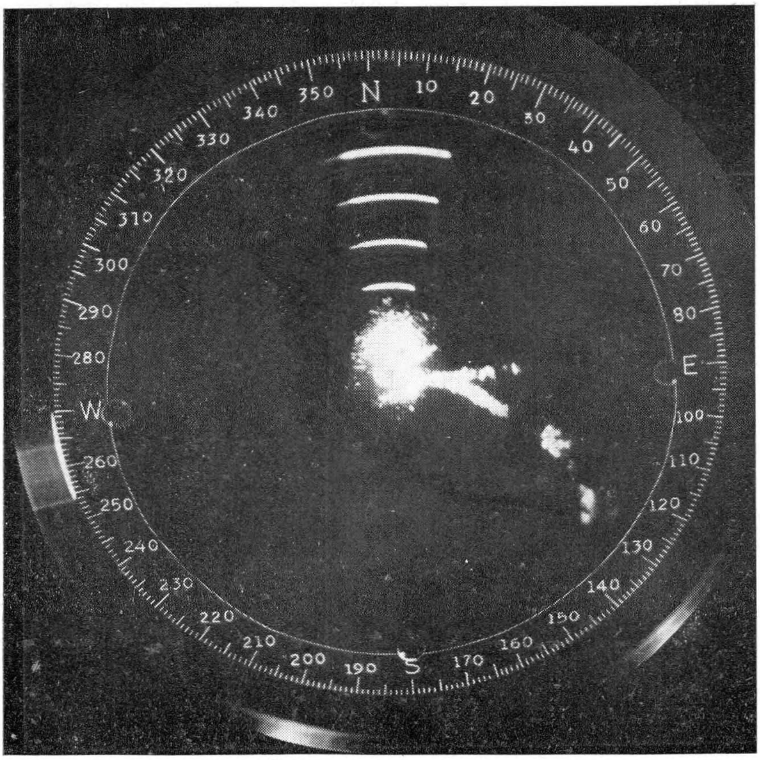

FIG. 11 *c*
PPI-scope photograph. — Position : 21° 35',3 *N.*, 158° 19',9 *W.*

ments is dependent on both experience and sufficient theoretical knowledge of radar principles.

A second and newer method of radar piloting employs the VPR (virtual PPI reflectoscope). This device, by the use of mirrors, seemingly coincides an image of a specially prepared chart* (*fig.* 8) on the same plane as the scope (*fig.* 7a).

By the proper adjustment of the chart the charted features, such as shorelines, hills, and light-houses, may be " matched " with the corresponding scope signals (*fig.* 9). Since the center of the scope represents the ship, its position on the chart is the position of the ship. This provides a constant determination of position within 60-200 yards and eliminates the necessity of plotting ranges and bearings. The radar chart and the navigators chart may be gridded for the convenient interchange of data.

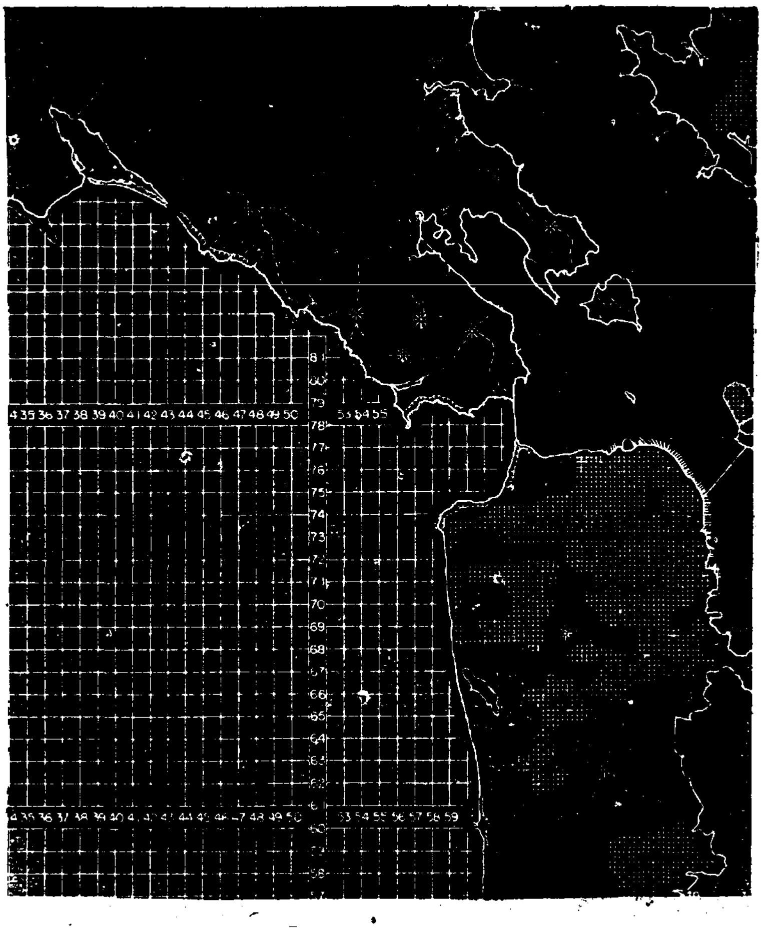

FIG. 8

Section of Radar Piloting (VPR) Chart of the type prepared by U.S. Hydrographic Office

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*Prepared by the Hydrographic Office, U.S. Navy.

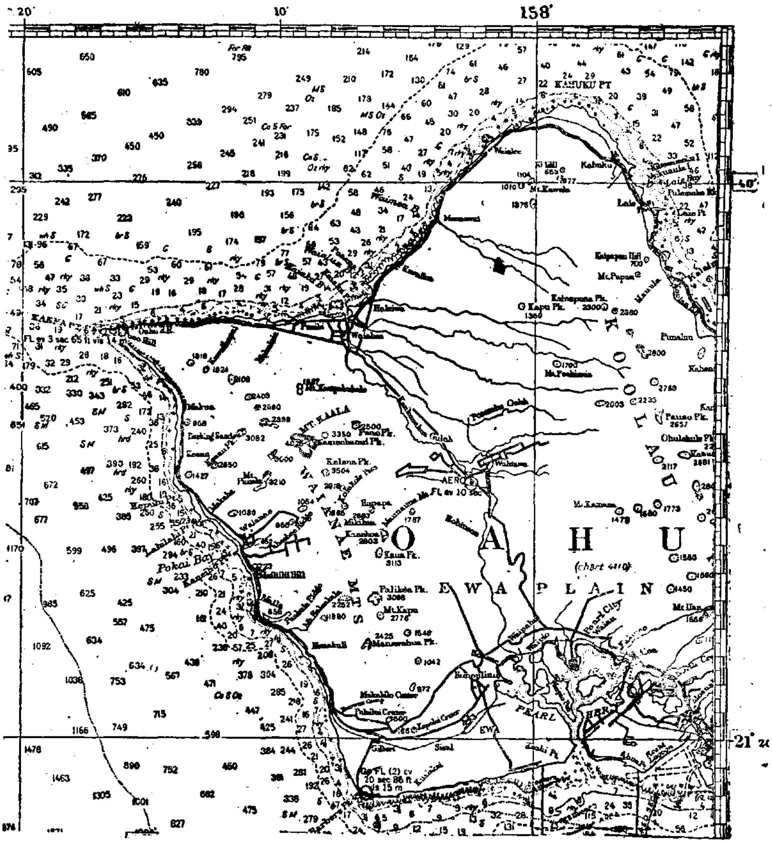

FIG. 10
Chart of area in which the Scope photographs were taken of fig. 11a, 11b *and* 11c

Additional applications.

In addition to piloting, radar is of great value as an anti-collision device. The presence of other ships may be detected at such a distance as to provide opportunity to determine, by plotting, their course and speed in order to avoid collision.

Radar will also detect the presence of icebergs. However, it is not wholly reliable in the detection of growlers and floes that are large enough to damage vessels.

The accuracy of radar at the present stage does not meet the standards required for hydrographic surveying. It is possible that future developments may provide precision equipment which will be of value in this field.

The chief disadvantage of radar at this time is the cost and complexity of the equipment. However, this is offset for large vessel installations by the greater advantages of convenience and safety provided.