# USE OF RADAR AND RADAR BEACONS IN HYDROGRAPHIC SURVEYING

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1.—Standard U. S. Navy shipboard and aircraft radar equipments have been used successfully as survey instruments by the *U.S.S. Tanner* while conducting a hydrographic survey of the East Coast of Mexico during 1947. In selecting the type of electronic equipment to be installed in the *Tanner*, the following features were considered :—

a) *General suitability of the equipment for use in surveying.*—The usual problem of the survey vessel is to fix its position anywhere in the area under development quickly and accurately by determining its bearing or distance relationships to known control stations. These control stations must be easily recognizable by the shipboard personnel, and distinguishable from the topographic features around them. Also, measurements to more than one control station must be made simultaneously for a fix, or for fix checking. The *Tanner* electronic surveying equipment provides the necessary positive identification of control stations by the use of transponder beacons at the control stations, and permits the measuring of simultaneous ranges and bearings to four control stations by the use of the four plan position (PPI) indicators on board.

b) *Accuracy of the equipment.*—Since it was planned to use only the radar ranges to two or more control stations for fixes because of the relative accuracies of radar ranges and bearings, it was desirable to obtain equipment that would provide accurate ranges to the greatest possible distances. With the radar equipment now installed, ranges accurate to about twenty yards can be measured to distances of 50,000 yards and ranges accurate to about 100 yards can be measured to distances of 75,000 yards.

c) *Operation of the equipment.*—Since the electronic system required installation of the transponder beacons at the control stations, it was essential that the beacons be portable, and light enough to be installed on triangulation towers, lighthouse structures, or small craft. The beacons consist of the transponder which weighs about 50 pounds, and its power supply, which weighs about 175 pounds. Since it as usually possible to install the power supply on the ground beneath the beacon structure, its weight was not considered to be excessive.

d) *Availability of equipment.*—Since immediate delivery was required, only existing equipment available in sufficient quantities was considered.

2.—The equipment procured and installed on the *Tanner* consisted of the long range, surface search type radar set, with Precision Plan Position Indicators, and the best current radar transponder beacons :—

a) This radar is designed primarily for surface search, navigation, and its frequency is in the vicinity of 3,000 mcs. It has an " A " oscilloscope and a PPI (Plan Position Indicator), and has two range bands, of 0 to 15,000 yards, and 0 to 75 000 yards, respectively. These two scopes can be read to the nearest 100 yards. Two radar sets of this type are installed on the vessel, so that it is possible to observe simultaneous ranges to two different targets up to 75,000 yards.

b) The Precision Plan Position Indicator is designed to be used with most standard equipment, and can be read more accurately than the above basic radar. It has a conventional 5 inch PPI having ranges of 4, 20, 80 and 200 miles plus a five inch " B " oscilloscope. Upon this five inch " B " scope appears a sector 40 degrees wide and 4,000 yards long, in a clear and amplified form which covers the entire scope. Horizontal and vertical electronic lines indicate range and bearing respectively. To determine the range and bearing of any target the range and bearing cranks are turned until the target is centered on the screen at the intersection of the central range and bearing marks. The range can then be read directly from the counters, which read to the nearest 20 yards up to a maximum of 50,000, and the bearing, either true or relative, can be read directly from the PPI bearing card. Four of these Precision PPI's are installed, and can be connected with either basic radar, singly or in combination. With these four repeaters it is possible to observe simultaneous ranges to four different targets up to 50,000 yards.

c) The radar transponder beacon consists essentially of a receiver and transmitter both operating near 3,000 mcs. Both transmitter and receiver are tuned to the same frequency used by the master radar. During operation, the master radar emits a pulse which is picked up and amplified by the beacon receiver, which in turn keys the transponder transmitter, causing it to emit a signal which is picked up, amplified, and fed into the oscilloscopes, either of the master radar indicator, or to the remote PPI's by the master radar receiver. These beacons return a sharp, well-defined signal to the radar. The signal is crescent-shaped, and covers 150-200-yards of range. By decreasing the receiver gain it is possible to eliminate all normal returns from the oscilloscope except that from the beacon. It is possible also to code the return signal from the beacon, for positive identification of the station, by the addition of a coder unit. A power source is required to operate the beacons with 115 volts, 400-2400 cycle AC, and 12 or 24 volts DC. The *Tanner* used gasoline driven generators to obtain these voltages, and used the same source to charge the batteries used by the portable communication equipments.

d) Satisfactory two-way communication between the ship and shore stations was maintained by using radio telephone equipment. Voice communications were used exclusively, so that experienced radio operators would not be required to man the stations.

3.—During the shakedown cruise of the *Tanner* in the Gulf of Maine in November of 1946, the accuracy of the fixes obtained by using the radar beacons set up ashore at known control stations, in conjunction with the radar equipment aboard, was tested. The radar ranges from the ship to the beacons were compared with the actual ranges, obtained by locating the vessel's position by the intersection of theodolite cuts from known shore stations, or by the observation of two sextant angles from the ship. In all cases, the radar ranges, the sextant angles, and the theodolite cuts were observed simultaneously. All data were plotted on a scale of 1:40 000 and the error of each radar range was determined. From the results of this test, it was concluded that the *Tanner* combination of radar and precision PPI repeaters, with the radar beacons, was suitable for use in offshore hydrographic development on scales no larger than 1:40 000, since the mean error of the radar ranges amounted to about 30 yards.

4.—In the hydrographic survey of the East Coast of Mexico in 1947, the *Tanner* further developed the technique of using radar equipment as a survey instrument for position fixing. The problem during this survey was to develop the area out to the 1000 fathom curve, which was shown on existing charts to be about 40 miles offshore. The area was developed satisfactorily, by adoption of the technique described herein, on scales of 1:80 000 and 1:160 000.

5.—Geodetic control was established in the area by *Tanner* personnel, from the 19° parallel to Point Delgada Light. Astronomical position, azimuth and base-line measurements were observed in the Vera-Cruz area, and a net of triangulation stations was expanded to cover the survey area. For efficient advance by the expedition as a whole, it was necessary for the observers and computers to complete their work far enough ahead so that the boat sheets could be prepared in sufficient time to prevent delay of the sounding units. This phase of operations was complicated by the necessity of supplying intimate control for construction of boat-sheets on scales of 1:3 000 and 1:10 000, for use by sounding boats developing the harbor of Vera-Cruz and the approaches thereto. However, except for the initial period in the area the actual sounding operations were never unduly delayed for lack of boat-sheets.

6—The survey as a whole progressed in a northerly direction from the 19° parallel, with the lines of soundings run in directions normal to the coast line, on northeast and southwest courses. As the triangulation and inshore hydrographic development by sounding boats using visual control progress northward, the offshore development of the area out to the 1000 fathom curve was prosecuted by the

*Tanner* and the three small survey vessels, *U.S.S. Harkness, U.S.S. Simon Newcomb, U.S.S. James M. Gilliss,* using radar control, checked, where practicable, by visual control for fixes on the inner ends of the lines. The transponder beacons were established along the coast at intervals of about 15 miles. These beacon stations were established at triangulation stations, on lighthouse structures, or on vessels moored to offshore buoys. In all cases, the antennae were positioned at the station as high as practicable, and with little or no eccentricity. Voice radio communications were maintained at all times between the *Tanner* and the beacon stations. Generally, two men were assigned to each station, to maintain and operate the beacon.

7.—Although the plotting of a range from each of two beacon stations resulted in a fix, it was considered desirable to keep three beacon stations in operation, in order to check the accuracy of the fix by means of a third range, and to guard against the loss of adequate fix data because of the failure of one of the beacons. Therefore, three beacon stations were always in operation; and as the sounding work progressed northward, passing beyond the effective range of the southernmost beacon, this beacon site was vacated by the beacon party, who then set up their equipment at a new station, farther north than any of the others.

8.—On board the *Tanner* during these radar controlled sounding operations, fixes were obtained at regular intervals, usually every five minutes, as the fathometer recorded the depths. Each of three precision PPI indicators was manned by an operator who tracked the beacon assigned his indicator continuously, by turning the azimuth and range cranks in such a way that the crescent-shaped signal from the beacon was kept centered at the intersection of the central azimuth and range electronic lines on the " B " scope. Each operator stopped cranking when the recorder for the operation sounded a buzzer signal, as indication of the instant that a fix was required; and read aloud the range registered on his counters. The recorder then entered the value of each range in the sounding book; and the plotting officer immediately plotted the fix. The plotting officer used a beam compass of suitable length, and an accurate diagonal scale, to plot each of the ranges. Short arcs, representing the ranges from each of the beacon stations, were drawn on a transparent overlay of the sheet, and the intersection of the arcs was adopted as the ship's position. This method of plotting permitted an evaluation of the accuracy of the fix when more than two ranges were obtained, and enabled the plotter to determine the most probable track of the vessel during those times when only one range was obtained. This occurred at the outer ends of the lines, when the ship was beyond the maximum range of the beacon, and at times when the beacons were not operating properly. At the conclusion of each day's work, the adopted track of the vessel was pricked through the overlay sheet to the boat-sheet and the soundings were entered on the track lines, from the processed sounding books.

9.—Aside from the usual operations described above, several interesting techniques in the use of radar equipment as a surveying instrument were introduced. As mentioned previously, radar beacon stations were established on small vessels moored offshore, sometimes in water as deep as 100 fathoms. At such a station, of course, additional error in the fixes was introduced because of the swinging of the vessel with the wind and the tidal currents. To reduce this error as much as possible, the vessel was moored to a buoy anchored with a 5000 pound sinker. The scope of chain and wire joining the sinker and the buoy was reduced as much as practicable, with the cable-water depth ratio at about 1 ½ to 1. In addition, the beacon vessel was hauled taut to the buoy. The resulting radius of swing about the anchor position, which was the point plotted on the sheet was about 200 yards in the case of water depth of 100 fathoms. To eliminate as much of this error as possible, the position of the beacon was assumed to be on the circumference of a circle around the anchor position, with a radius of 200 yards. For each hour of operation, the beacon vessel radioed its mean heading, and that heading determined the sector of the circumference from which the ranges obtained during that hour were plotted. It is believed that this method held the fix error resulting from ranges to the ship-borne beacons, to about 100 yards. The value of having control beyond the limit of 75,000 yards from the coastline offset the decrease in accuracy.

10.—To locate the anchor positions for these ship-borne beacons, several methods were used. If visibility conditions permitted, the moored vessel itself was located by intersection of theodolite cuts from triangulation stations in the area, and the anchor position was plotted at the proper distance, which depended upon water depth and cable length, and in the proper directions, which was indicated by the heading of the vessel at the time of the observations. When visibility conditions prevented the location of the vessel by visual cuts, the beacon vessel was located by the use of radar in several ways, the most common of which was the location of the anchor position by the intersection of two or more radar ranges from operating beacons, at the instant the anchor touched bottom. This was generally practicable since the *Tanner* laid all the moorings for the beacon vessels. However, at least one mooring was laid at a time when no beacons were in operation until after the beacon vessel had been moored, and when visibility conditions prevented the location of the vessel by theodolite cuts. This beacon station was located, after shore-based beacons and ship-borne beacon were in operation, by having the *Tanner* take numerous simultaneous ranges to all three beacons as she steamed on courses approximately perpendicular to the lines between the moored vessel and each of two shore-based beacons. As the *Tanner* approached the line between a shoreside beacon and the newly moored ship beacon, the sum of the ranges to these beacons approached a minimum; and after the *Tanner* crossed the line, the sum of the ranges to the beacons gradually increased. The minimum sum, obtained by plotting a curve, was adopted as the true distance between the previously-located shore beacon and the ship beacon. Since distances were measured from the ship beacon to each of two shore-based beacons, the ship beacon was located at the intersection of the two distances. Several measurements for the minimum sums were determined for each line, and the results indicated an accuracy of about 10 yards. This method is particularly valuable for the location of triangulation stations, islands, shoals, lighthouses or buoys, too far offshore for location by the usual visual triangulation methods, and presents a technique for establishing a baseline of low order accuracy, in areas where the measurement of a precise baseline would be uneconomical, or in areas where the use of a preliminary distance value would expedite the production for boat-sheets for sounding operations, without delay. Since the error in measuring such a line would be the same, regardless of the length of the line, the degree of accuracy obtained would increase with the line measured, up to a theoretical maximum of 50 miles, which is the sum of the limits of the VF equipment.

11.—The use by the *Tanner* of standard radar equipment for hydrographic surveying in 1947, was successful in that areas were developed by radar control that could not have been developed without the use of numerous floating signals, or of radio acoustic ranging. It was economical in that existing standard military equipment was employed throughout, without expenditure of time and money for specialized equipment. However, specialized electronic devices designed primarily for surveying have been developed; and in the future the hydrographic surveyor will use these electronic devices, not only for positioning a sounding unit, but also for obtaining triangulation data.