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RADAR MEASUREMENTS OF CAMOUFLAGED SCHNORKEL

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ABSTRACT

Measurements of radar echoes from a camouflaged schnorkel on the submarine ex-U-3008 were made with AN/APS-20 (10.4 cm), AN/APS-2F (9.1 cm) and AN/APS-15A (3.2 cm) radars. The measurements were made from 3 April to 10 April 1947, in the Atlantic Ocean at a point about 75 miles east of Norfolk, Virginia. Measurements were of a quantitative type which allowed results to be interpreted in terms of the fundamental characteristics of the radar target, independent of the performance characteristics of the radar. Data were recorded photographically, pictures of both the PPI and A scope being taken simultaneously. The data were taken on tracking runs only.

The results showed that the superior performance of the APS-20 radar against schnorkel in these tracking tests was compatible with the increased sensitivity of this system. Hence it is indicated that no new factors are involved in its performance against schnorkel.

As a by-product of these tests, it was found that floating debris in the area of the schnorkel operation produced considerable confusion and difficulty in locating the schnorkel.

This is an interim report on this problem; work is continuing.

RADAR MEASUREMENTS OF CAMOUFLAGED SCHNORKEL

INTRODUCTION

In some recent tests performed by the Operational Development Force,* it was established that the AN/APS-20 radar was very effective in search against camouflaged submarine schnorkel. This result is of great operational importance, inasmuch as previous airborne radars had proved to be entirely ineffective in such applications. In view of the earlier disappointing results with other radars, the successful performance of the AN/APS-20 was beyond expectations, and hence the possibility arose that some new factors, hitherto unsuspected, were involved.

To compare results obtained with radars on different frequencies, the relative target characteristics on these frequencies must be known, in addition to the radar systems parameters. Arrangements were made, therefore, for additional tests in which the radar characteristics of the schnorkel target could be determined on X, S, and AEW bands. These tests were performed in conjunction with the Operational Development Force. The target was the ex-U-3008, and measurements were made with three airborne radars, AN/APS-20, AN/APS-2F, and AN/APS-15A. The last two radars were installed in a PBM airplane used by the Laboratory for quantitative radar measurements from the air. To make similar quantitative measurements on the APS-20, the necessary additional measuring equipment was installed in each of two PB1-W's of VX-4 squadron equipped with this radar. The tests were run between 3 April and 10 April 1947 at a point approximately 75 miles east of Norfolk, Va. Tracking runs were used exclusively in these tests, so that the additional factors involved in the initial detection of the target do not enter the measurements.

In this report, a brief description of the techniques and instrumentation used in obtaining quantitative measurements of radar area will be given. This will be followed by a presentation of the results obtained and the conclusions to be drawn from the analysis that has been made. The results show that when the measured radar target characteristics are combined with the radar systems characteristics, the measured performance agrees, within experimental accuracy, with that to be expected on the basis of these characteristics. It is indicated, therefore, that no new factors are involved in the performance of the APS-20 radar against submarine schnorkel.

MEASUREMENT TECHNIQUES

The measurement of radar area from airborne equipment presents problems not usually encountered with ground-based radars. The chief difficulty arises from the rapid

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* ComOpDevFor SECRET Fifth Partial Report on Project No. Op/V26/F42-1 and Amendment to Project No. Op/V32/A16-3(17), entitled "Evaluation of the Capabilities and Limitations of Airborne Early Warning Equipment (Detection of Camouflaged Schnorkel)" dated 10 February 1947

motion of the plane and the consequent necessity for making all measurements very quickly. This practically rules out manual methods. For some time there have been under development at this Laboratory techniques for quantitative measurement of radar echoes, in which the data are recorded on photographic film for later analysis. The operator is thereby relieved of all data-recording duties, and can concentrate his attention on the adjustment of the radar and the necessary associated measuring equipments.

A block diagram of the measuring setup used is shown in Figure 1. In addition to the standard components of the radar, remote A and PPI scopes are added, each fitted with a camera to photograph the presentation. The camera used was the Fairchild Type A recording camera, which takes single-frame pictures in synchronism with the rotation of the radar antenna. For these tests, a tripping mechanism was installed which kept the shutter of the camera open during a 60° (or 30°) sector. This sector could be centered either in the forward or aft direction, so that data could be recorded either on approach or receding runs. Thus, all signals appearing during this sector were recorded on the film. Only the A scope films were used for the actual measurement data. The PPI films were very helpful in the analysis work when several signals appeared on the A scope simultaneously. This proved to be particularly important, since considerable ship traffic in the area of operations made the location and tracking of the schnorkel target quite difficult at times.

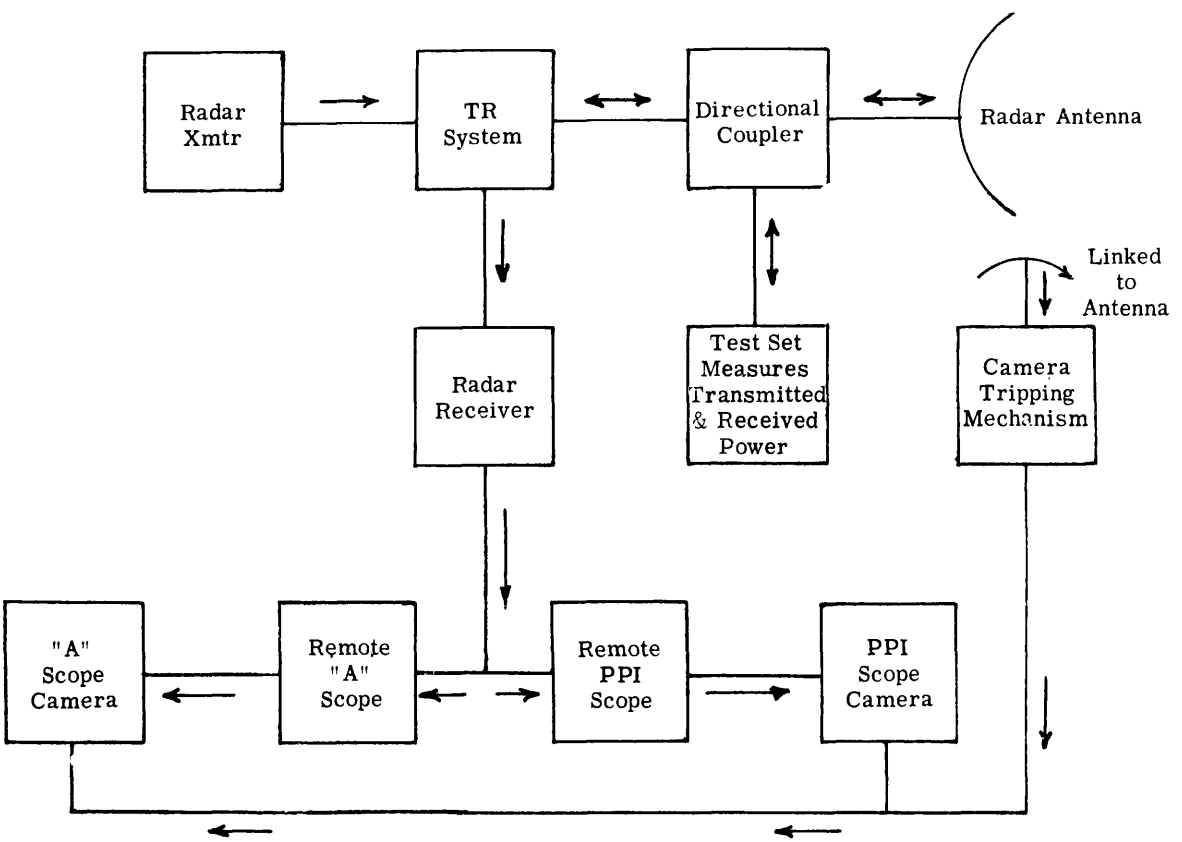

Fig. 1 - Block Diagram of Measuring Setup

In addition to the normal radar echoes which appear on the A scope, a comparison signal from a pulsed signal generator (test set) was introduced into the radar through a directional coupler near the antenna. The amplitude of this comparison signal could be adjusted by varying the attenuator dial of the test set. Through a selsyn repeat system, a replica of the test set attenuator dial was introduced into the field of view of the A scope camera. In this way, each A scope frame carried a comparison pip of known magnitude. During the entire series of measurements, the radar receiver was run on manual gain control, so that the A scope deflection was approximately proportional to the signal input. A direct calibration of the input-output relationship, however, was obtained by setting the test set pip at various levels, and taking an A scope picture for each level. This calibration procedure was repeated each time the gain of the radar receiver was changed. The entire calibration procedure took less than one minute to make.

To interpret the measurements recorded on the film in terms of the target characteristics, certain other parameters of the measuring setup must be known. These include the over-all antenna gain, the insertion loss of the directional coupler, and the loss of the transmission line or wave guide connecting the test set to the directional coupler. It is also necessary to know the transmitted power of the radar. If the transmitted power is measured on the same test set which generates the calibration pip, the test set level need not be calibrated on an absolute basis. The antenna gain, directional coupler, and line losses enter in such a way that they can all be lumped into a single factor. This calibration factor was determined for each radar installation by transmitting a signal through an antenna of known gain arranged at a short distance in front of the radar antenna, and measuring this signal on the radar by comparison with the local generated test set pip. In this calibration, again, it is not necessary to know absolute signal levels, since only the ratio of transmitted to received signal is involved in the calibration.

The technique described above is particularly advantageous because it eliminates the operating efficiency of the radar equipment at the time of measurement. What is measured, in fact, is the strength of the radio wave in front of the receiving antenna in terms of the strength of the transmitted wave of the radar. The maximum range measured on a radar, on the other hand, depends not only on the characteristics of the radar target but also to a very great extent on the system parameters of the radar, as well as its relative operating efficiency at the time of measurement. Rather wide variations in the operating efficiency can take place even during the course of a single day. For example, during the scheduled measurements reported here, the transmitted power of the APS-20 varied over a range of 2 to 1. The APS-15A used was afflicted with low power output and poor minimum detectable signal throughout these tests, as a result of which the maximum range obtainable on the schnorkel was considerably below normal. In spite of this fact, the calibration and measurement procedure described above enabled measurements to be obtained of the target characteristics, which can be used to compare performance on various frequencies and to compare with normal radar operation. In addition, the measuring equipment permits the actual power output and minimum detectable signal to be determined.

Three radars were used in the measurements. A PBM aircraft carried two of these radars, an APS-2F (9.1 cm) and an APS-15A (3.2 cm). The third radar was the APS-20 (10.4 cm) installed in a PB-1W aircraft of VX-4 squadron. Two such aircraft were fitted out with the measuring equipment described above, one being used at a time, the other serving as standby in case of equipment failure. Measurements were made on all three radars on 7 and 8 April 1947; additional measurements on the APS-20 were made on 10 April. Measurements were also scheduled for 3 and 4 April, but heavy seas prevented the taking of any data on these days.

The U-3008 submerged between 0900 and 1200 and between 1400 and 1700 each day of operation. While submerged, the submarine proceeded in normal schnorkel operation on a fixed course at a speed of about 6 knots. During the morning run, this course was up sea; during the afternoon run, the course was down sea. The periscope was up at all times during which measurements were made. The top of the schnorkel was about four or five feet out of the water, on the average. During the period that the submarine was operating on schnorkel, the PBM and PB-1W planes carrying the radars made measurements of the radar echo. The measurements were made on tracking runs only. After location of the submarine, the plane flew radially outward on a fixed heading to maximum range. The course was then reversed and the measurements made on a closing course. Runs were made up, down, and cross-sea, at altitudes of 500, 1000, and 2000 feet.

In addition to the radar data measured aloft, the submarine recorded schnorkel height, the state of the sea, and direction and force of the wind just prior to and following each period of submerging. Arrangements were also made to obtain stereo-photos of the sea surface, from which additional data relative to the state of the sea, such as wave height and length, etc.,could be determined. For this purpose the two stereo pictures must be exposed simultaneously. The stereo camera actually used, however, was not of this type, so that the photographs could not be used for a more quantitative evaluation of the state of the sea than that estimated from the surface. In addition to wind and sea observations from the U-3008, additional observations of these and other weather data were made by the USS LEARY, which was stationed in the neighborhood of the submarine for this purpose.

RESULTS OBTAINED

The methods of obtaining the radar area of ship targets and the results obtained on a wide variety of ships have been given in a series of NRL reports.† A brief discussion of the phenomena involved will be given here, inasmuch as this discussion will be helpful in the discussion and interpretation of the results obtained.

Under standard propagation conditions, the vertical coverage diagram of a radar for low angles of elevation consists of a series of lobes which represent the interference pattern between direct and ground-reflected rays. For a concentrated target such as an airplane, the position of each lobe depends on the height of radar and target, and on the range. If the target could be maintained in the maximum of any one lobe at all ranges, then the power of the received echo would vary as R^{-4}. This would require that the aircraft approach the radar at an approximately constant angle of elevation. For a fixed altitude of approach, however, the received echo would pass through successive maximums and minimums as the target flew through the various lobes of the interference pattern. For ranges greater than that of the first lobe maximum, the target "slides" under the first lobe, and the resulting variation of power with range is as R^{-8}.

A ship, however, is a distributed rather than a concentrated target, so that the above phenomena are modified to some extent. In particular, the successive maximums and minimums are filled in so that the variation of echo power with range is a continuous one. At ranges shorter than that corresponding to the condition where the first lobe maximum lies at the top of the ship (in this case schnorkel) the echo power increases as R^{-4}. For greater

† NRL Reports RA3A213A, R-2232, R-2295, R-2332, R-2466, R-2467, R-2524, and R-2793

ranges, however, the target "slides" under the first lobe of the vertical pattern just as in the case of an airborne target, so that the variation of echo power with range again is as R^{-8}. A plot of received power versus range of the ship results in a plot of the type shown in Figure 2. For the particular case where the "ship" is a submarine schnorkel, the target area is so small that some radars will not detect the target at ranges great enough to lie in the R^{-8} region. This is true, for example, in the case of the APS-2F and APS-15A. The APS-20, however, has sufficient sensitivity so that it can track a schnorkel into the R^{-8} region. In comparing maximum ranges obtained on these three radars, therefore, it is necessary to take this fact into account.

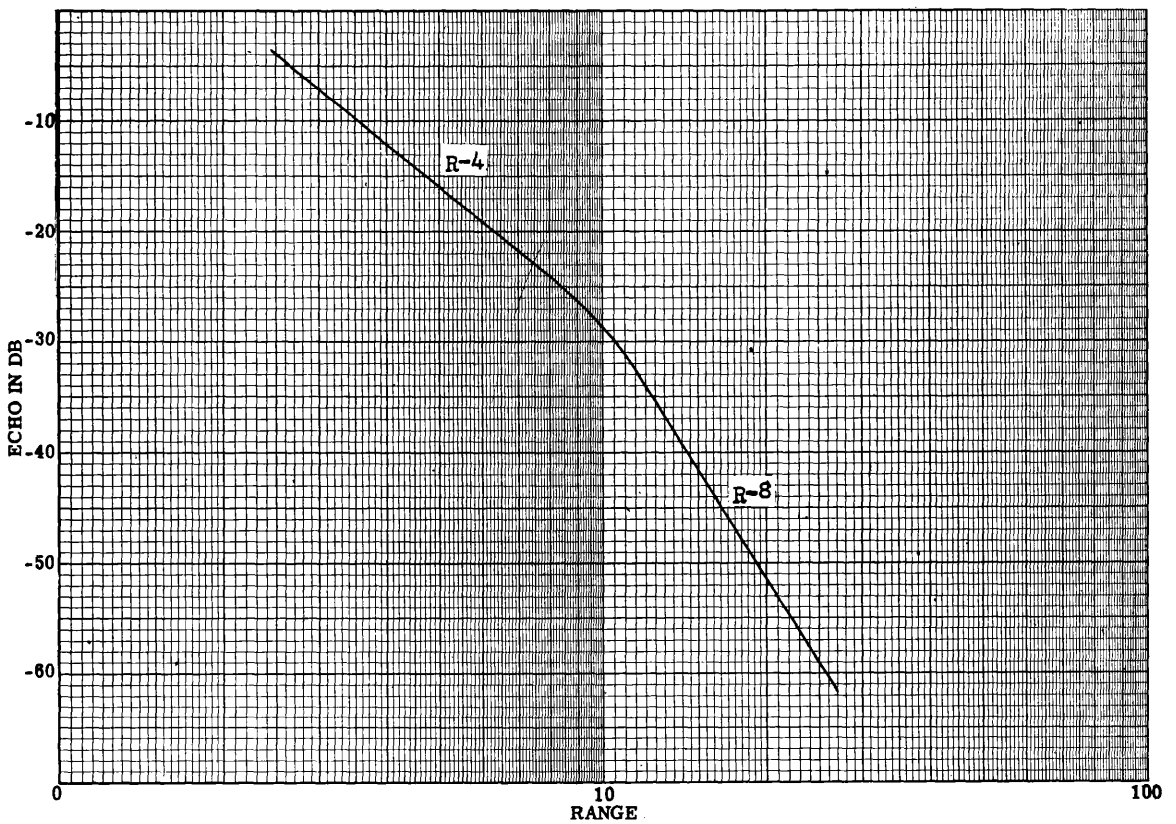

Fig. 2 - Typical Plot of Strength of Radar Echo Versus Range

Although in principle it is possible to determine the radar area of a ship or other surface target from a single quantitative measurement of the radar echo, it is necessary in practice to make a sequence of measurements at various ranges, and then to draw a line representing the envelope of these measurements, from which the radar area is calculated. This is because the radar area of the target depends critically upon its orientation, or aspect. Fluctuations of the radar echo result from roll and pitch of the target. A series of measurements made on a tracking run enable these variations to be smoothed out, and values to be obtained corresponding to those which are effective in the search problem. Extensive measurements made on ship targets under controlled conditions of aspect have

shown that the results are in good accord with the simple theory described above. By making use of the general features of this theory, it is possible to extract fairly reliable figures of radar area even when measurements at only a few values of range are available.

Tables I and II contain the data on radar areas of the schnorkel obtained from the measurements on APS-20 and APS-15A, respectively.‡ From table I the average radar area of the schnorkel at 10.4 cm is 7.6 square meters, while from table II the average radar area on 3.2 cm is 390 square meters. The ratio of these two values is 17 db. This ratio appears to be quite high on first thought, but is explainable by the nature and disposition of the schnorkel camouflage on the U-3008 and the way in which the schnorkel was illuminated by the two radars.

Laboratory measurements of the reduction in reflection produced by the Wesch type of absorber placed over a metal backing yield the following results: 14% (-8.5 db) at 3.2 cm, 5% (-13 db) at 9.1 cm, and 6% (-12.2 db) at 10.4 cm. These measurements indicate that the absorbing material has about 4 db greater reflection on 3.2 cm than on 9.1 cm and about equal reflection on 9.1 and 10.4 cm. However, an NRL letter report§ discloses that only the top 19 inches of the schnorkel on U-3008 was covered with absorbing material, and, furthermore, that this material had been painted a number of times. The result of the painting is to shift the band of maximum absorption upward in wavelength and to impair its absorbing qualities somewhat. The effect of having only the upper portion of the schnorkel covered with absorbing material is most pronounced on 3.2 cm, for at all of the ranges involved in the measurements reported here, the first lobe of the vertical coverage diagram lay below the portion of the schnorkel covered with the absorber. Hence, the schnorkel was practically uncoated insofar as the measurements on the APS-15A radar were concerned. It is to be expected, therefore, that the measured radar area at 3.2 cm would be considerably higher than that on 9.1 and 10.4 cm. This, in fact, turns out to be the case, and the average ratio of 17 db between the radar areas at 3.2 and 10.4 cm is of the order to be expected under the circumstances. For 10.4 cm, on the other hand, the first lobe maximum lay at or above the top of the schnorkel, so that the partial covering of the schnorkel was located most strategically to produce a maximum reduction of reflection. On the other hand, the difference between the radar areas on 9.1 and 10.4 cm is expected to be small. Measurements of the camouflage coating on the schnorkel of the U-3008 were made at Norfolk Navy Yard immediately prior to the schedule of radar measurements reported here. The results of these measurements have been reported.**

Table III summarizes the maximum ranges actually recorded on the film records. For the APS-2F radar, table III lists the two longest ranges observed on the PPI frames. Both of these ranges were recorded on inbound cross-sea flights on 8 April between

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‡ On the APS-2F, a relay associated with the camera-tripping mechanism gave intermittent trouble, with the result that most of the time the shutter on the A scope camera failed to hold open for enough of the 60° normal sector to record the echo from the target. This difficulty also spoiled some of the PPI records. As a result, no useful data were recorded on the A scope of the APS-2F, and the information recorded on this radar was limited to maximum ranges recorded on the PPI film.

§ NRL SECRET Letter Report on Camouflage Coating on U-3008, File no. S-S67-5/25 (1341), S-1300-79/47, Serial no. 6256, dated 14 April 1947

** Cf. fn. §

TABLE I

DATA OBTAINED ON AN/APS-15A RADAR (3.2 cm)

Date	Time	Altitude (feet)	Schnorkel aspect	Schnorkel height (feet)	Radar area of schnorkel (square meters)	State of sea	Direction of observation
7 Apr	1402	500	095°	4	300	1	cross sea
7 Apr	1413	500	090°	5	96	1	cross sea
7 Apr	1420	500	280°	5	190	1	cross sea
7 Apr	1438	1000	100°	4-5	38	1	cross sea
7 Apr	1451	1000	225°	5-6	107	1	cross sea
7 Apr	1458	1000	270°	5-6	480	1	cross sea
7 Apr	1541	1000	009°	5	270	1	up sea
7 Apr	1555	2000	120°	5-7	212	1	cross sea
8 Apr	1119	500	000°	4	425	3	cross sea
8 Apr	1142	500	350°	4	1700	3	cross sea
8 Apr	1507	500	090°	4	300	3	up sea
8 Apr	1515	1000	270°	3-4	1350		down sea
8 Apr	1538	1000	090°	4-7	135		up sea
8 Apr	1605	1000	180°	4-5	340		cross sea
8 Apr	1626	2000	180°	4	150		cross sea
8 Apr	1643	2000	090°	4	170	1	up sea
					Avg. 392		

TABLE II

DATA OBTAINED ON AN/APS-20 RADAR (10.4 cm)

Date	Time	Altitude (feet)	Schnorkel aspect	Schnorkel height (feet)	Radar area of schnorkel (square meters)	State of sea	State of wind	Direction of observation
8 Apr	0936	500	270°	6-9	4.5	3	1	cross sea
10 Apr	1138	500	115°	4	7.9	3,4		down sea
8 Apr	1450	500	090°	4	2.8	3		down sea
8 Apr	0945	500	270°	6	13.2	3	3	up sea
8 Apr	1141	500	295°	4	7.3	3	3	down sea
8 Apr	1631	1000	270°	4	2.0	1		down sea
8 Apr	1618	1000	270°	4	8.5	1		up sea
8 Apr	1549	1000	270°	4	13.3	1,3		up sea
7 Apr	1527	1000	040°	5	11.5	2,4	3	cross sea
					Avg. 7.6			

TABLE III

MAXIMUM RANGES OF PHOTOGRAPHED SCHNORKEL ECHOES

Radar	Altitude (feet)	Schnorkel Aspect	Schnorkel Height (feet)	Number of Runs Included	Range of Measurable Pips of Greatest Range
AN/APS-15A	500	all		6	9-10 nautical miles
3.2 cm	1000	all		9	10-11 nautical miles
	2000	all		3	11 nautical miles
AN/APS-20	1000	side		3	24-25 nautical miles
10.4 cm	1000	bow and stern		3	25-26 nautical miles
	500	all		5	25-26 nautical miles
AN/APS-2F	500	bow	6	1	9.2 nautical miles
9.1 cm	500	stern	4	1	11.5 nautical miles

1100 and 1200. Greater ranges might have been recordable, in view of the intermittent functioning of the camera-trip mechanism, although the 11.5 miles pip was minimally weak. The 11.5-mile range was found on the first frame in which any target on the schnorkel bearing could have been seen, since the camera shutter was closed on the other frames for this bearing. The next useful frame after the 11.5-mile frame showed the schnorkel at 10.6 miles, where it should have been. Only one frame corresponding to a greater range than 9.2 miles was properly exposed on the run on which the 9.2-mile range was obtained; this frame corresponded to a range of about 9.6 miles, and no schnorkel pip was observable there.

The data of table III can be supplemented by the reports of the operators of the radars. The APS-2F and APS-15A were in the same plane, and the operators were in constant telephone communication with each other. Because of the inferior performance of the APS-15A during these tests, the APS-2F consistently obtained greater maximum ranges on the schnorkel than did the APS-15A. Most of the time the schnorkel pip was detected on the APS-2F radar one or two miles farther out than on the APS-15A. In fact, the APS-2F was often used to assist the operator of the APS-15A in locating the schnorkel echo and in guiding the pilot of the PBM onto the proper radial course. The operator of the APS-2F claims a maximum observable range of about 12 miles on the schnorkel, whereas the APS-15A operator claims maximum ranges of about 10 or 11 miles. These statements agree very well with the film-recorded data. On the particular runs for which the APS-2F radar obtained maximum ranges on the film of 9.2 and 11.5 miles, the greatest ranges on the film for the APS-15A were 9.2 and 10.5 miles respectively. Furthermore, the APS-15A operator stated that the weakest film-recorded echoes were certainly no stronger than the weakest visually observable echoes.

The NRL operator on the APS-20 claims a visually observed range of 35 or 36 miles on the schnorkel, but such ranges were not detected in any of the sequences of the A scope photographs. The PPI photographs on this radar were available only for the runs of 8 April,

owing to a camera jam on 7 April and fogging of the film exposed on 10 April, which took place either in the plane or during development. The PPI frames corresponding to the 8 April runs did not show schnorkel pips at greater ranges than those of the A scope sequences.

Table IV gives numerical data of the average systems characteristics of the three radars during the tests, as obtained by the measurements. In this table the peak transmitter power was determined by dividing the average output actually measured on the test set by the duty cycle, and correcting for the direction coupler and transmission line losses. The antenna gains are the rated values, that for the APS-15A being for the full parabolic dish without insert. A correction for antenna tilt of the APS-20 is included in table IV, since a surface target at distances involved in these tests will be above the nose of the antenna beam as the system is now installed. It is estimated that the target would be about 1.5 db down from the main beam, so that the echo would be 3 db weaker than if the nose of the beam were pointed right at the target.

The last two columns in table IV give the relative superiority of the APS-20 radar over the other two radars (as used in these measurements). In aggregate, the APS-20 was about 45 db better in over-all sensitivity than the APS-15A used in these tests, and about 24 db better than the APS-2F.

TABLE IV

COMPARISON OF RADAR SYSTEMS USED IN SCHNORKEL MEASUREMENTS OF 7, 8, AND 10 APRIL 1947

	APS-20	APS-15A	APS-2F	APS-20 APS-15A (decibels)	APS-20 APS-2F (decibels)
Peak transmitted power, kw	600	4	50	21.8	10.8
Antenna gain	1100	3200	400	-9.3	8.8
Receiver sensitivity (decibels below 1 watt)	126	101	120	25.0	6.0
Wavelength, centimeters	10.4	3.2	9.1	10.2	1.2
Antenna beam tilt, degrees	-3.5°	0	0	-3.0	-3.0
Totals, (decibels)				44.7	23.8

It is now possible to compare the maximum ranges actually observed with those values calculated from the measured radar areas and systems characteristics. Due allowance must be made for the fact that the APS-20 is capable of tracking a target beyond the R^{-4} region into the R^{-8} region, as explained in connection with Figure 2. If this were not done, the performance of the APS-20 would appear to be inferior. Thus, the maximum recorded range of about 26 miles on the APS-20 becomes extrapolated to a range of 58 miles on the basis of an R^{-4} variation throughout. This figure of 58 miles, rather than the recorded value of 26 miles, is the proper one to use for comparison with the maximum recorded ranges on the APS-15A and APS-2F. When allowances are made for the measured differences between the radar parameters of the three systems, the maximum observable range

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on the APS-2F is equivalent to a range of 46 miles and the maximum observed range on the APS-15A is equivalent to a maximum range of 54 miles. Comparing these with the extrapolated range of 58 miles for the APS-20 it is seen that they are mutually compatible within the accuracy to be expected from this type of measurement. Hence, one is justified in concluding that no unexpected physical phenomena are encountered in the problem of tracking schnorkel with radar.

It should be emphasized that this conclusion is directly applicable only to tracking runs such as were made in these tests. In the search problem, on the other hand, additional factors of target acquisition are involved. These factors, some of them psychological in nature, include antenna beam width, scan rate, method of echo presentation, etc. Furthermore, the schnorkel was tracked to ranges beyond the sea clutter in the present experiment, whereas in a search procedure the range may decrease to the point where the sea clutter is the limiting factor in detection. Investigations into some of these aspects of the schnorkel search problem are in progress.

On 8 April considerable difficulty in target acquisition was experienced by the APS-20 operators, because of many spurious targets in the vicinity of the schnorkel echo. These spurious echoes were traced to refuse floating in the water. The refuse appeared visually to be trash, such as small boxes or cans dumped by a passing ship and carried by sea currents through the test area. The echo from this trash was formed of many pips and covered a considerable area. The magnitude of the pips was sufficient to make impossible a separation of the schnorkel echo by magnitude considerations. It would appear that some such scattering of small floating targets would be useful to a schnorkeling submarine as a defensive action against radar location after detection, similar to the use of airborne "window" as an aircraft radar countermeasure.

CONCLUSIONS

The results of these tests indicate that no new factors are involved in the operation of the APS-20 radar against schnorkel. They also indicate the importance of camouflage coatings on the lower exposed portions of the schnorkel in order to reduce possibility of detection on X-band radar. Finally, the possibility of a schnorkeling submarine escaping location by expelling refuse to create confusion should not be overlooked.

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