NRL REPORT NO. R-3138

SEA TRIALS
OF THE MTI CONVERSION UNIT
FOR SC-SK SERIES SEARCH RADAR

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NAVAL RESEARCH LABORATORY

Washington, D.C.

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SEA TRIALS OF THE MTI CONVERSION UNIT FOR SC-SK SERIES SEARCH RADAR

by

T. H. Chambers

June 1947

Problem No. 39R02-24

Approved by:

L. A. Gebhard,
Superintendent
Radio Division II

Commodore H. A. Schade, USN
Director
Naval Research Laboratory

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ABSTRACT

The MTI Conversion Unit for SC-SK Series Radar was installed in the SK-3 Radar System aboard the USS E-LSM 446, and four aspects of its performance under actual fleet operating conditions were evaluated. It was found that:

1. The ship's full speed (12 knots) had no noticeable effect on MTI performance.
2. The addition of MTI to the system had negligible effect on the detection range for plane speeds of 180 knots or faster, and only slight effect for speeds down to 120 knots.
3. In 24 runs made through clutter, an average of 80 percent hits were made on the PPI; thus, essentially solid coverage was obtained.
4. Fairly heavy, though not severe conditions (30° double amplitude roll and 8° to 10° pitch) where encountered, and had no effect on the performance of the mercury delay line.

AUTHORIZATION

The development and test of the MTI Conversion Unit was authorized by NRL problem S1055R-C (39R02-24), initiated in response to BuShips letter serial no. C-916-9630 to Director NRL, dated 21 February 1945.

PROBLEM STATUS

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

[redacted]

SEA TRIALS FOR THE MTI CONVERSION UNIT FOR SC-SK SERIES SEARCH RADAR

INTRODUCTION

THE MTI SYSTEM

During the latter months of the war, the problem of intercepting Kamikaze planes became rather severe, especially during amphibious operations. The enemy had learned the effectiveness of coming in low over land masses for his attacks on ships participating in landings. This procedure not only rendered him invisible optically, but, because of the land clutter on the radar scopes, protected him against radar detection. To combat these tactics, the MTI Conversion Unit for SC-SK Series Radar was developed at this Laboratory. Although the details of this system have been fully discussed elsewhere, *,† a general description will be given here.

The SC-SK series radar is a 200 mc air-search radar designed primarily for early warning service. Although it is now as least obsolescent (if not obsolete), it was, during the war, a very important part of the defense of the Fleet against air attack. It consistently gave warning of high-flying aircraft at ranges of 75 miles and more, and was capable of ranges of 50 to 60 miles on aircraft at lower altitudes. With the addition of MTI, it becomes a system capable of very reliable performance against planes from a minimum range (dependent on altitude) of 1 or 2 miles out to the maximum range, quoted above with almost solid coverage in spite of areas of clutter.

Two parameters of the system were changed when MTI was added. The pulse length was reduced from the original 6 microseconds to 2 microseconds and the pulse repetition frequency was increased from the original 60 cps to 500 cps. Otherwise, system parameters remained unchanged. The MTI system was of the coherent pulse doppler type, and employed a mercury delay line in the cancellation unit. To obtain maximum sub-clutter visibility, a linear i-f system, limited at 30 db above noise level, was used in conjunction with a "coho" at intermediate frequency and a phase detector. To insure stability over long periods of operation, the cancellation system used automatic time balance. Although it was originally planned to use automatic amplitude balance, the system was found in actual use to be sufficiently stable to make this unnecessary.

The additional components added to the SC-SK system upon conversion to MTI were housed in two separate units. The modulator for the transmitter is shown mounted beside the transmitter in Figure 1, and the MTI Conversion Unit itself, is shown mounted with PPI's and A scope in Figure 2.

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* NRL Report No. R-2723 titled "The MTI Conversion Unit for SC-SK Series Radar" to be issued about 15 November 1947.

† NRL Report No. R-3065, "A pressurized Mercury Delay Line for Fleet Service," June 1947.

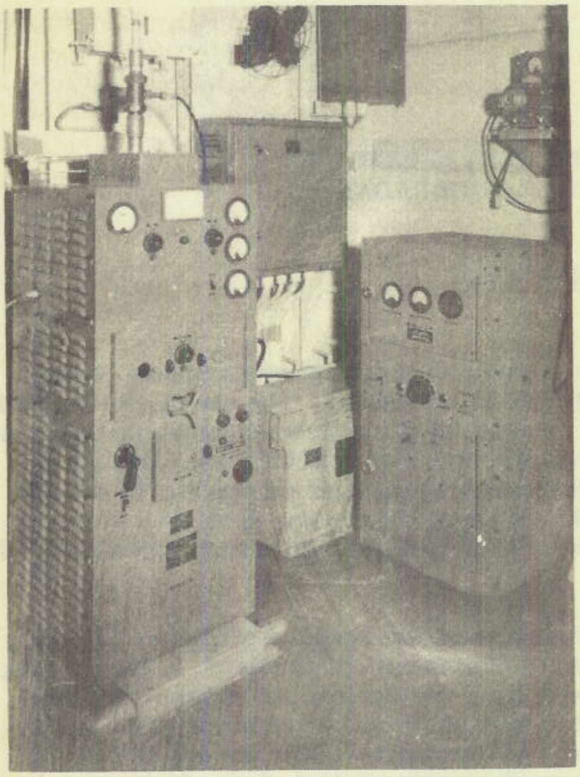

Fig. 1 The Modulator Unit Mounted Beside the SK Transmitter Aboard the USS E-LSM 446

OPERATIONAL TESTS

Although the MTI system had been given a thorough test ashore, a test afloat was arranged in order to verify, under fleet operating conditions, the answer to four questions: Will the ship's motion cause any deterioration of clutter cancellation? Does the addition of MTI result in any loss in maximum range? Will the MTI provide solid coverage in clutter areas under actual fleet operating conditions? Will the mercury delay line perform properly under the adverse conditions of fleet operation?

The test was made aboard the USS E-LSM 446 in the lower Chesapeake Bay and in the open ocean off Cape Hatteras between the dates of 10 February 1947 and 20 February 1947.

INSTALLATION

THE USS E-LSM 446

The USS E-LSM 446, assigned to this test by OpDevFor, is a converted LSM in which four radar rooms and an electronics work shop have been fitted on the tank deck. Radar No. 1 is forward and contains the control consoles for the radar aboard the ship (including the control console for the SK). Radar No. 2 is just aft of radar No. 1 and is used as CIC. The electronics workshop, the Wardroom, radar No. 3 (not at present used for radar work) and radar No. 4 follow in the order named. The SK transmitter was located in radar No. 4.

INSTALLATION OF THE MTI CONVERSION UNIT

The MTI Conversion Unit was mounted in radar No. 1 beside the control console for the SK radar as shown in Figure 3. Although the conversion unit was originally designed to mount in the space occupied by the SK PPI (and thus take its place in the control console), it was felt that such a mounting would, in the case of a short operation like the present test, entail unjustifiably extensive revision of the system, both at the installation of the MTI and at its removal. Thus, to avoid this extensive revision, the MTI Conversion Unit together with a separate A scope unit was mounted entirely separate from the original control console, and the unused PPI and A scope were simply disconnected from the system. Figure 2 shows these two units. The lower unit in the center of the picture is the MTI Conversion Unit. The upper unit, also in the center of the picture, is the separate A scope, which will be recognized as a revised SC-SK series A scope. This scope has been modified to operate at a repetition rate of 500 cycles. The receiver has been removed (a new receiver is contained in the MTI Conversion Unit), and an expanded sweep unit for the A scope substituted in its place. The other two units visible in this picture are two Model VE PPI's. The unit on the left was used to display the "normal" signal; the one on the right was used to display the MTI signal. All units were shock mounted, the PPI's on their normal shock mounts, and the MTI Conversion Unit, along with the A scope, on a set of mounts borrowed from an SK PPI.

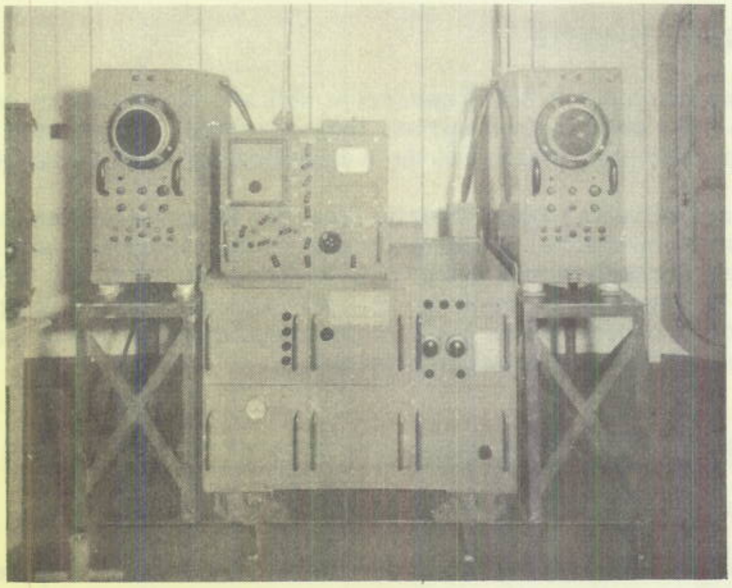

Fig. 2 The MTI Conversion Unit for SC-SK Series Radar and Associated Scopes Aboard the USS E-LSM 446

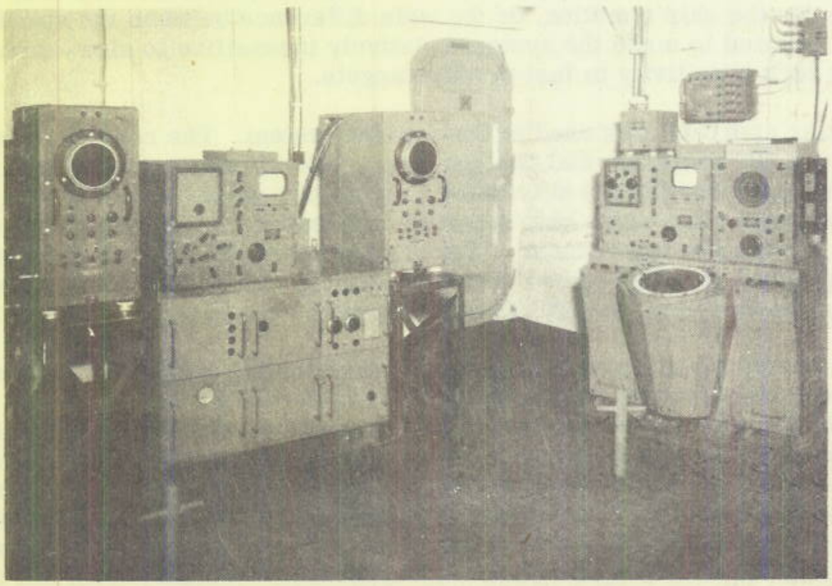

Fig. 3 The MTI Conversion Unit for SC-SK Radar Mounted Beside the SK Control Console Aboard the USS E-LSM 446

INSTALLATION OF THE MODULATOR

Figure 1 shows the modulator mounted beside the transmitter in radar No. 4. The modulator was not shock mounted, but was welded directly to the deck. Such a mounting was possible because the entire modulator was designed to take shock and vibration directly with the exception of the tubes, which were individually shock mounted inside the unit.

INTERCONNECTION OF UNITS

The interconnection of the MTI Conversion Unit and the modulator was made by means of three cables -- two coaxial lines and one four-wire line. These were conveniently installed in an open cablé rack which ran the entire distance from Radar No. 1 to Radar No.4.

Power for both units was taken directly from the SK radar system so that the normal power switches were operative. To supply power to the conversion unit and its three associated scopes, connection was made to the terminal board on top of the antenna control unit (visible in Figure 3 on top of the SK-PPI) where power is brought into the system. For the modulator, connection was made to the transmitter terminal board inside the box visible at the base of the transmitter in Figure 1.

EFFECT OF SHIP'S VELOCITY ON MTI PERFORMANCE

THEORETICAL CONSIDERATIONS

Because of the double path nature of radar transmission, the doppler effect on which MTI is based is identical for motion of the target and for motion of the radar system. Thus the MTI system is equally sensitive to the motion of the vehicle on which it is mounted and to motion of the target. Two possibilities for eliminating the effect of the ship's motion exist for an air-search radar such as the SK. Either special circuits may be included to compensate for the ship's motion, or the wide difference between the speeds of ships and planes may be used to make the system relatively insensitive to slow-moving targets while maintaining high sensitivity to fast moving targets.

The latter approach was used in the present system. The repetition rate of the system was set at 500 cycles so that the speed for peak response came at 407 miles per hour. Figure 4 shows a theoretically determined sensitivity-versus-speed curve. It will be seen that responses due to the ship's motion will ordinarily be down 20 db or more when the system is set up in this manner. The highest speed possible with present Navy ships (the flanking speed of a high-speed destroyer) will give a response down about 15 db. The full speed of the test ship, the USS E-LSM 466 gave a response down about 23 db.

Before attempting to arrive at any conclusion regarding system performance under these various conditions of motion, it is necessary to consider the methods normally used in adjusting the controls on the conversion unit. The receiver is tuned using the normal channel. The "coho" is then tuned to what is estimated as zero beat, using the MTI channel and A Scope with the through-channel gain reduced to zero. Next the through-channel gain is increased to the point of best balance. The trigger is then adjusted to best balance after which the through channel is retrimmed to best balance. Finally the MTI i-f gain control is adjusted to give a noise height approximately equal to the residual uncancelled clutter. It is this step which affects the over-all system performance. Its effect comes about because it is in reality an adjustment of the system limit level to match the performance of the cancellation system.

Consider the effect of a change in limit level on system performance. If the system limit level is set at a given figure, say 30 db above noise, the sub-clutter visibility will increase linearly as clutter strength increases up to a few db below this limit level. It will then remain constant (because of the use of a phase-sensitive detector) as clutter level increases. Thus sub-clutter visibility will be, under any condition of adjustment, a few db less than the limit level, and, since the limit level is being effectively reduced to remove components which are left uncancelled because of ship's motion, it becomes apparent that the sub-clutter visibility will always be a few db less than the value of the loss in sensitivity," given by Figure 4 for the speed at which the ship is moving.

In view of these considerations and the fact that the sub-clutter visibility of the SC-SK MTI system is about 27 db when the system is not in motion, the approximate sub-clutter visibilities that can be expected are:

At rest	27 db
"Full Speed" of E-LSM 446 (14 knots)	23 db
Normal fleet operating speeds (25 knots)	18 db
"Flank Speed" of high speed Destroyer (40 knots)	14 db

TEST PROCEDURE

A complete series of sub-clutter visibility measurements at speeds from rest to about 40 knots would be the best test of the effect of the ship's motion on the MTI. The results could then be plotted as a curve of sub-clutter visibility versus ship's speed. Unfortunately such a test could not be made on the present equipment, since no ship capable of the necessary 40-knots speed was available. In fact, the full speed of the ship used was only 14 knots, and a simple observation of the effect of the ship's full speed on clutter cancellation had to suffice. For this, the MTI was put into operation with the antenna headed broadside (so that radial velocity was zero), while the ship was running down the Potomac River to its operating area, in the Chesapeake Bay. The antenna was then started in normal rotation, and the effect of the ship's speed (then 12 knots) on cancellation was noted.

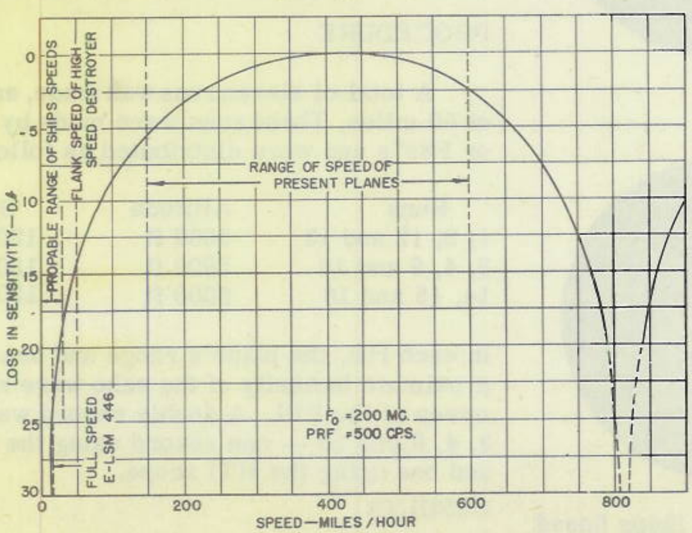

Fig. 4 Graph Showing Loss in Sensitivity Versus Speed
SC-SK MTI

RESULTS

The results of this test are shown in Figure 5. The top photograph shows the normal scope and gives an idea of the clutter in the area. The lower photograph shows the MTI scope. Since the ship was proceeding on course 140° true at 12 knots, some clutter was expected on bearings 140° and 320°. The photograph shows a very slight amount of residual clutter at about 310° true. Otherwise, the scope is almost clean. The echo at 14 miles on 288° true is an unidentified plane. The radial line at 275° true in the lower photograph is not due to a defect in the MTI system. The camera used to make these photographs was defective and this radial line resulted from failure of the shutter during winding of the film.

Although this test does not show conclusively that the table given above is correct, it does show that, as this table indicates, clutter residual just begins to show up at 12 knots.

RANGE TESTS

PURPOSE OF TESTS

The presence of a coherent signal along with an echo in a receiver has long been known to have possibilities for increasing receiver sensitivity. In the use of coherent cw in the MTI, no particular effort has been made to take advantage of these possibilities: however, it has been estimated that the peak sensitivity of the MTI system is one or two db better than the sensitivity of the normal system. The range test was intended primarily to compare the relative range of the MTI and Normal systems to find out whether any increase in MTI range was noticeable, or whether some unknown factor was reducing MTI ranges. Along with a check on maximum range, it was thought desirable to check MTI range at more than one speed to establish the accuracy of the curve of Figure 4.

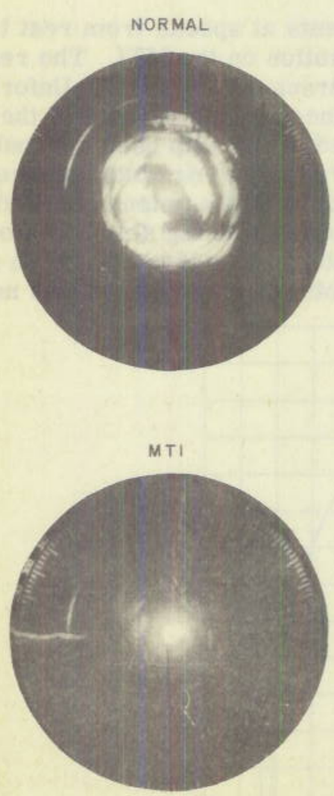

Fig. 5 Effect of Ships Speed on SC-SK MTI Performance (Ships Speed 5 Knots)

PROCEDURE

A total of eleven runs was made, each over a distance of 50 miles. These runs were made by pairs of F6F's or F8F's and were distributed as follows:

Runs	Altitude	Speed
1, 2, 12 and 13	5000 ft	120 Knots
3, 4, 9 and 10	5000 ft	180 Knots
14, 15 and 16	2000 ft	120 Knots

In each run, the plane's range and bearing and the approximate intensity of the echo were recorded for every sweep of the PPI. A double record was made on runs 3, 4, 9 and 10 -- one record using the normal scope, and one using the MTI scope.

RESULTS

Figure 6 shows the results of this test plotted on a chart showing the antenna lobe structure. In making this plot, coverage was considered "solid" if, in a given range interval of 1 mile, the echo was readable one-half the time for the average of all runs of the series.

It will be noted from Figure 6 that for a target speed of 180 knots the MTI performance and normal performance are the same and that the range of each is about the maximum to be expected at this altitude. Figure 4 shows, however, that at 180 knots (215 mph), the MTI is approximately 2 db below its peak sensitivity. Thus, this test indicates that the peak sensitivity of the MTI system is about 2 db above that of the normal system.

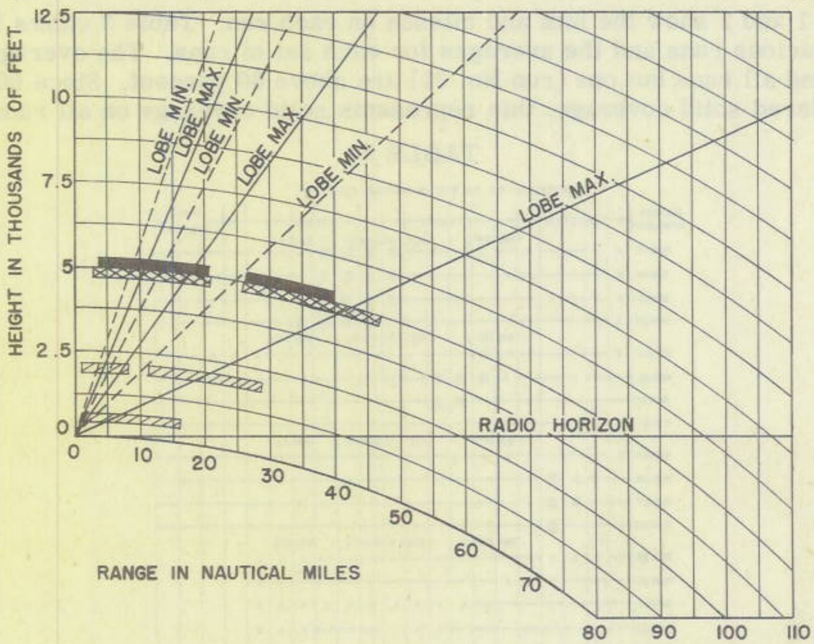

Fig. 6 Vertical Coverage of SK-3 Modified for MTI

Figure 6 also shows that MTI range is about 15 percent less at 120 knots than at 180 knots. This represents a less in sensitivity of about 3 db and checks very well with Figure 4 which shows a loss of 5 db for 120 knots as against 2 db for 180 knots.

ANTI-CLUTTER TESTS

PURPOSE

This test simulated the conditions under which MTI will be most needed and investigated the system coverage under these conditions.

SITE OF TEST AND CLUTTER LEVELS

A site at the mouth of the Rappahannock River was chosen as representative of clutter conditions which would be encountered in making landings on large islands or other land masses. Fairly solid clutter of about 60-db strength extended from 2 miles to 4 miles, of about 40 db strength from 4 miles to 7 miles, and of about 25 db from 7 miles to 11 miles.

TEST PFOCEDURE

Twenty-four runs between the ship and a point 12 miles out were made in this clutter by pairs of F6F's or F8F's at altitudes of 250, 500, 1000 and 1500 feet and at speeds of 140 and 180 knots. On each run the observer recorded, for every sweep of the PPI, the planes' range and bearing and the estimated echo strength.

RESULTS

Tables 1 and 2 show the hits and misses on each run. Table 3 shows the percentage hits for the various runs and the averages for each set of runs. The average track is 80 percent, and all runs but one (run No. 31) are above 60 percent. Since 50 percent hits is considered solid coverage, this represents solid coverage on all runs but one.

TABLE 1

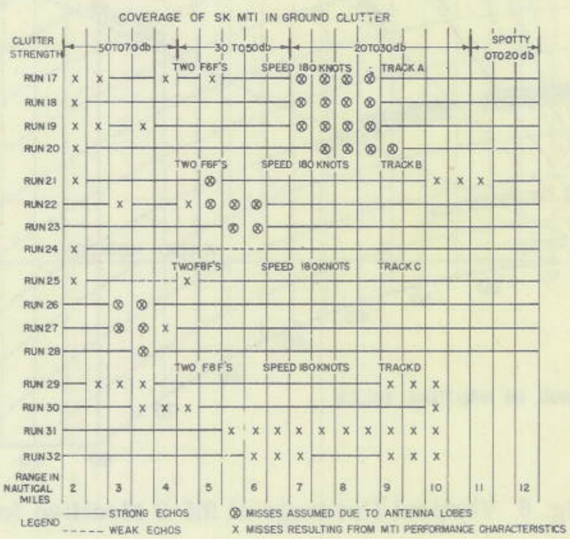

TABLE 2

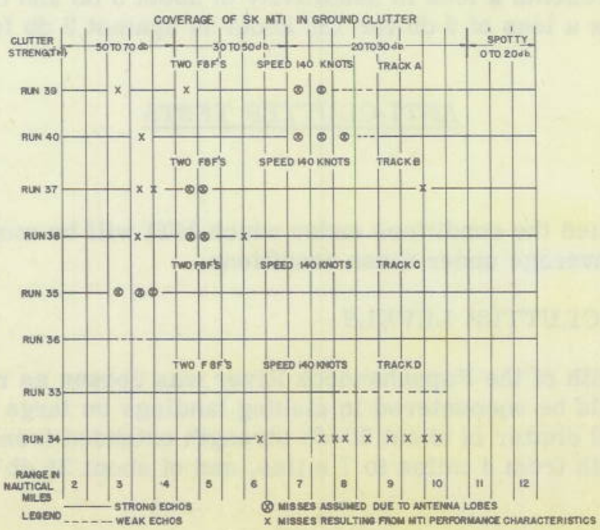

TABLE 3

SK MTI COVERAGE

Run No.	Total No. of PPI Sweeps	Total No. of Misses	Percent Coverage
Two F6F's: Track A - 180 Knots			
17	21	8	62
18	21	5	76
19	21	7	67
20	21	5	76
Average	84	25	70
Two F6F's: Track B - 180 Knots			
21	21	5	76
22	21	5	76
23	21	2	90
24	21	1	95
Average	84	13	85
Two F6F's: Track C - 180 Knots			
25	21	2	90
26	21	2	90
27	21	3	86
28	21	1	95
Average	84	8	90
Two F6F's: Track D - 180 Knots			
29	17	6	65
30	17	4	77
31	17	10	41
32	17	6	65
Average	68	26	62
Two F8F's: Track D - 140 Knots			
39	26	4	85
40	26	4	85
Average	52	8	85
Two F8F's: Track B - 140 Knots			
37	26	5	81
38	26	4	85
Average	52	9	83
Two F8F's: Track C - 140 Knots			
35	26	3	88
36	26	0	100
Average	52	3	94
Two F8F's: Track D - 140 Knots			
33	21	0	100
34	21	9	57
Average	42	9	78
Average of all runs	518	101	80

Although Table 3 shows the performance which may be expected in actual use of the system, Table 4 is of more importance as a test of the MTI itself. This latter table is similar to Table 3 except that all misses due to the antenna lobe structure (See Figure 7) have been eliminated leaving only those due to the characteristics of the MTI itself. The percentage hits (averaged for all runs) has increased to 87.

TABLE 4

SK MTI COVERAGE

Run No.	No. of PPI Sweeps Considered	No. of Misses Due to MTI	Percent Coverage
Two F6F's: Track A - 180 Knots			
17	17	4	76
18	17	1	94
19	17	3	82
20	17	1	94
Average	68	9	87
Two F6F's: Track B - 180 Knots			
21	20	4	80
22	18	2	89
23	19	0	100
24	21	1	95
Average	78	7	91
Two F6F's: Track C - 180 Knots			
25	21	2	90
26	19	0	100
27	19	1	94
28	20	0	100
Average	79	3	96
Two F6F's: Track D - 180 Knots			
29	17	6	65
30	17	4	77
31	17	10	41
32	17	6	65
Average	68	26	62
Two F8F's: Track A - 140 Knots			
39	24	2	92
40	23	1	96
Average	47	3	94
Two F8F's: Track B - 140 Knots			
37	24	3	88
38	24	2	92
Average	48	5	90
Two F8F's: Track C - 140 Knots			
35	23	0	100
36	26	0	100
Average	49	0	100
Two F8F's: Track D - 140 Knots			
33	21	0	100
34	21	9	57
Average	42	9	78
Average of all runs	479	62	87

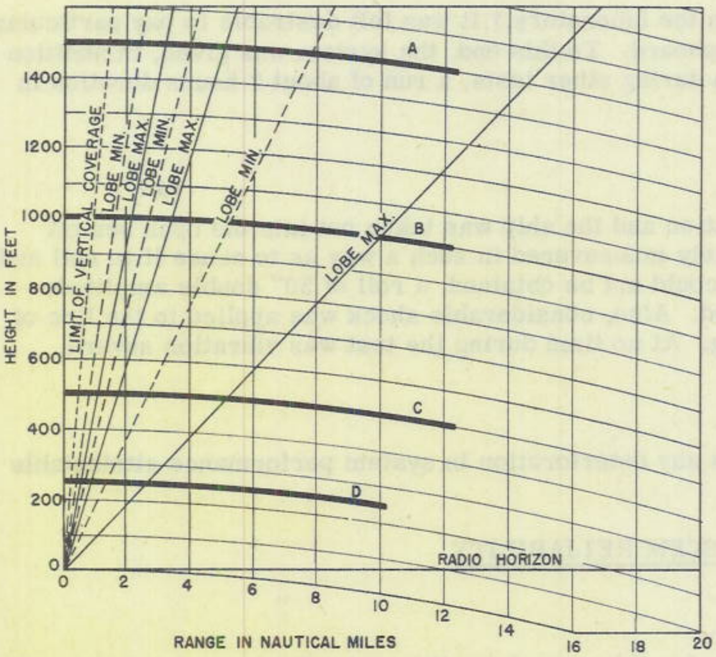

Fig. 7 Coverage of SK MTI in Ground Clutter

Unfortunately, as stated earlier, the camera used to record the results of these tests had a defective shutter and most of the pictures taken were lost. These casualties included all shots of the clutter runs some of which would have shown very effectively the action of the MTI. Figure 8, however, is a pair of pictures salvaged from a roll of film exposed earlier in the tests. The upper picture shows the normal performance while the lower pictures shows the MTI performance. Three planes can be seen in this lower photo -- one at 4.5 miles on 008° true, one at 9 miles on 240° true, and one at 11 miles on 275° true (weak). Unfortunately, none of these planes are in areas of solid clutter and hence they do not adequately illustrate the system performance. The clutter at the site where the clutter runs were made was considerably more solid than that of Figure 8.

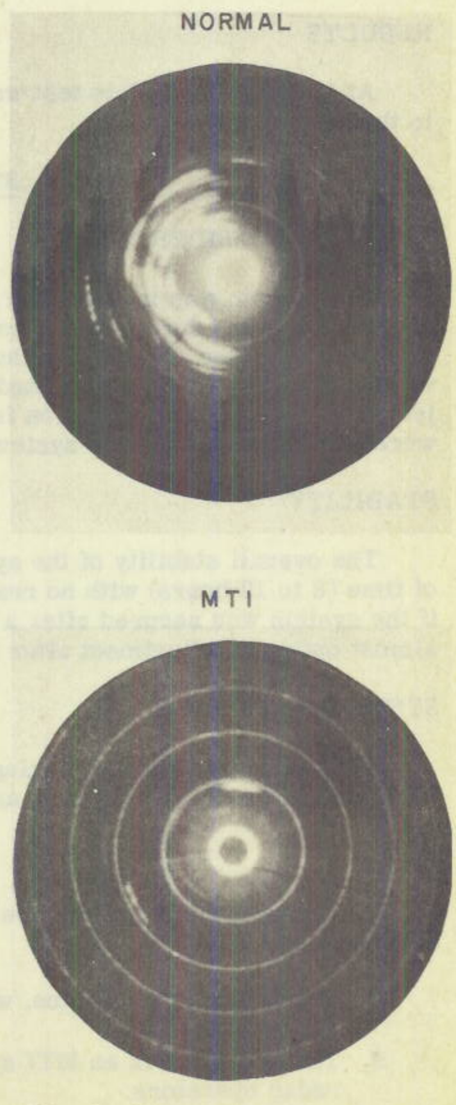

Fig. 8 Clutter Removal by the SK-MTI (20 mile range scale)

DELAY LINE TEST

GENERAL CONSIDERATIONS

In the past, MTI systems using mercury delay lines have been considered unsatisfactory on shipboard because of the possible effects of roll and pitch. The line used in the present system was designed specifically to withstand the adverse conditions of fleet service, and although this line had been subject to roll, vibration, and shock testing in the laboratory,† it was felt desirable to pay particular attention to its performance on shipboard. To this end, the system was given, in addition to its 60 hours of normal operation during other tests, a run of about 2 hours duration in rough seas.

TEST PROCEDURE

The system was put into operation and the ship was taken out into the open sea off Cape Hatteras where it was purposely maneuvered in such a way as to cause it to roll and pitch. Although severe conditions could not be obtained, a roll of 30° double amplitude and a pitch of 8° to 10° was attained. Also, considerable shock was applied to the line of by the slap attendant to the pitching. At no time during the test was vibration severe.

RESULTS

At no time during this test was any deterioration in system performance attributable to the delay line.

SYSTEM RELIABILITY

GENERAL CONSIDERATIONS

The system was in operation under the normal conditions for fleet service for a total of about 60 hours during these tests. Most of the time the ship was rolling 5° to 8°, and was pitching a few degrees. Although the Conversion Unit was not subjected to much vibration, the modulator (mounted in radar No. 4 directly above the engine room) was subjected to considerable vibration from the engines. Line voltage and frequency variations were normal for shipboard systems.

STABILITY

The overall stability of the system was excellent. It operated for extended periods of time (8 to 12 hours) with no readjustment whatsoever. Furthermore, it was found that if the system was secured after a days operation, it would, when again turned on, be in almost optimum adjustment after ten or fifteen minutes warm up.

SYSTEM FAILURES

Three failures occured during the 60 hours of operation of the system. Two of these were caused by defective parts, and one by inadequate ventilation.

CONCLUSIONS

Numerous conclusions can be drawn from these tests. Perhaps the most important of these are:

1. The mercury delay line, when properly designed and construced, is satisfactory for shipboard use.
2. The operation of an MTI system may be made simple enough to be handled by fleet radar operators.

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† Ibid.

3. Stability of an MTI system should present no particular problem. A system can be made to retain its adjustment over long periods of time.
4. Maximum radar range on MTI will be equal to maximum radar range on normal within the range of average plane speeds.
5. With MTI, "solid" coverage can be obtained through regions of rather heavy clutter.
6. With an MTI system such as the SC-SK MTI Conversion Unit, where the speed of peak response is in the neighborhood of 400 mph, no velocity compensation is needed for shipboard use.

ACKNOWLEDGMENT

The NRL personnel concerned with this problem wish to acknowledge the cooperation given them by the Office of the Chief of Naval Operations, OpDevFor, and the officers and men of the USS E-LSM 446. This exceptionally fine cooperation made the testing of this equipment not only a profitable undertaking, but also a pleasant one.

PRNC-3238-10-9-47-100