3 Research and Development of Testing Technologies for Radio Equipment
3-1 Performance Tests for Marine Radar

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Test procedures and acceptance criteria for the marine radars (IMO radars) are specified by the international standard IEC62388. IEC62388 has test items related to radar performance requirement in it. Detection ability tests, which are some of the radar performance tests, are needed to carry out under actual condition, using the specified targets by IEC62388, as far as possible. As one of our project “Development of a radio equipment testing method”, NICT has been developing the performance testing method for the Marine Radar. Summary and outcome of this project is explained.

1 Introduction

The National Institute of Information and Communication Technology (NICT) has, under commission from the Ministry of Internal Affairs and Communication (MIC), implemented type approval tests under the Radio Law, and conducted research and development on radio equipment testing methods associated with these tests. The objective of the type approval test is to verify that radio equipment, which is used in human lifesaving and rescue systems, has the capacity to maintain its rated functions and performance even in difficult environments of distress. The type approval tests are examinations based on international treaties established by the International Maritime Organization (IMO) and International Civil Aviation Organization (ICAO), for example[1][2].

“Radar installed on a ship for radio navigation,” also known as “marine radar” or “shipborne radar,” is one of the specified categories of type approval tests. Marine radar that falls under this category is also called IMO radar, because it is developed and manufactured in conformity with the requirement of IMO. The performance test’s criteria and procedure are stipulated in the international standard IEC62388, “Maritime navigation and radio communication equipment and systems -Shipborne radar-Performance requirements, methods of testing and required test results,”[3] and the type approval test in Japan is also implemented in compliance with it.

IEC62388 Specifies the minimum requirements for operation and performance of marine (shipborne) radar,

Table 1 Douglas sea states parameters listed in IEC62388 Edition 2.0 [3][6]

Douglas sea state	Mean wind speed kn	Significant wave height m	Sea state description
0	＜4	＜0.2	Flat, very calm
1	5 − 7	0.6	Smooth
2	7 − 11	0.9	Slight
3	12 − 16	1.2	Moderate
4	17 − 19	2.0	Rough
5	20 − 25	3.0	Very rough
6	26 − 33	4.0	High

NOTE 1 Significant wave height is defined as the average height (crest to trough) of the one-third highest waves. Individual waves and/or swell can combine to significantly increase the wave height and may result in obscuration of the target. This table only applies to waves formed by local wind.
NOTE 2 The table values are approximate due to the subjective nature of the sea state assessment.
NOTE 3 Sea swell will make assessment of wave height very difficult.

and the test method and required results. It was compiled based on the proposal adopted under the title of MSC.192 (79)[4] at IMO MSC79 (Maritime Safety Committee) in December 2004. The first version was published in Dec. 2007, and a revised version (Edition 2.0) was published in Jun. 2013.

Edition 2.0 gave more consideration to such items as: upgrade of target detection performance for safer ship navigation, compliance with ITU-R recommendations (especially spurious emission regulation), and integration with peripheral navigation equipment (e.g. Automatic Radar Plotting Aids (ARPA), Automatic Identification System (AIS), and others). Even among them, target detection performance was further considered to reflect a request that IMO seems to have made to the effect that the opinions of navigation officers should be taken into consideration. As a result, to confirm the detection performance, some conditions such as target description (e.g. presence of additional targets (land, coastline, ships, etc.)), sea conditions (i.e. sea-state: see Table 1) and sea clutter are added to the requirement. Therefore, performance tests are required to be conducted under more practical use conditions[5].

By the way, the Japanese Radio Law was also revised in line with the establishment of IEC62388 and enacted on the 1st of July, 2008. Revisions were made mainly to the radio equipment and type approval regulations. Since then, the type approval test in Japan is implemented in compliance with the performance requirements of IEC62388. For smooth and efficient implementation of the type approval test in Japan, NICT has made effort to design practically feasible test methods and improve the environment for them.

The requirements of the radar performance which is described in IEC62388 are classified into several classes such as "transmission and interference," "performance optimization and monitoring," "gain and anti-clutter functions," and "signal processing". Most of all performance tests should or could be conducted in an indoor test house (e.g. transmission frequency measurement and receiver sensitivity measurement). However, some of the tests need to be conducted on an open-air test site, because the radar under test needs to be installed on a shore-based test site or a test ship on the sea. This report places the main focus on open-air performance tests, and describes the studies that have been put into practice up to the present and their results.

2 Open-Air performance tests

2.1 Search and examination of measurement site

IEC62388 stipulates that radar performance tests will normally be carried out at test sites selected by the type test authority. Specific testing is required over sea and may be shore based or at sea on a test ship. These test sites provide an over water test range with test targets and the features required for specified tests. In addition, IEC62388 stipulates certain conditions on the range of first detection in minimal clutter (clutter means disturbances observed on the radar screen caused by sea clutter, rain and snow clutter, and other origins) as listed in Table 2. Therefore, performance tests must be carried out in an environment making it possible to observe targets like those described in Table 2.

Regarding the sea conditions for performance tests, some tests need to be conducted in a rough sea corresponding to the sea state level 2 to 5, as well as in calm and clutter-less sea. Therefore, the selected waters near the test site or around the test ship must allow not only continuous calm sea conditions, but also occurrence of higher sea states.

The subjects of the performance test include, in addition to the target detection performance described above, such performance items as fundamental radar accuracy (precision in terms of distance and direction), minimum range (minimum distance of target detection), range discrimination, and bearing discrimination. The test site must be selected so that it allows all these measurements or tests. The search and investigation of the test site was carried out not only with the type test authority but also with help from an advisor knowledgeable on radar applications.

In the earliest years, when the Radio Law was put into force, it was generally difficult to secure a shore-based test site (an appropriate location along a coastline) or reserve a ship for testing. In those days, a part of the parking area of Umihotaru (a man-made island of the Tokyo Bay Aqua-Line) was borrowed as a temporary test site, and measurements were made to detect the ship navigating nearby. However, the waters around Umihotaru are reliably characterized by calm continuation of marine phenomena, with a small number of test targets that can be used as a reference for examining detection capability, to say nothing of the uncontrollable variation of ship sizes and distances that change from time to time. It was concluded, therefore, that search and investigation was necessary to secure suitable shore-based test sites and test ships that can navigate off

Table 2 Reference targets listed in IEC62388 Edition 2.0 (Range of first detection in clutter-free condition) [3][6]

Target description [e]	Target feature height above sea level m	Detection range [f]	
		X-band NM	S-band NM
Shorelines [g]	Rising to 60	20	20
Shorelines [g]	Rising to 6	8	8
Shorelines [g]	Rising to 3	6	6
SOLAS ships (> 5,000 gross tonnage) [g]	10	1	11
SOLAS ships (> 500 gross tonnage) [g]	5.0	8	8
Small vessel with radar Reflector meeting IMO P.S. [a]	4.0	5.0	3.7
Navigation buoy with corner reflector [b]	3.5	4.9	3.6
Typical navigation buoy [c]	3.5	4.6	3.0
Small vessel of length 10 m with no radar reflection [d]	2.0	3.4	3.0
Channel markers [c]	1.0	2.0	1.0

a IMO revised performance standards for radar reflectors (resolution MSC.164(78)) – radar cross-section is defined as (RCS) 7.5 m^2 for X-Band, 0.5 m^2 for S-Band. The reflector used should not exceed the stated RCS by more than 50 %.
b Target is taken as 10 m^2 for X-band and 1.0 m^2 for S-band.
c The typical navigation buoy is taken as 5.0 m^2 for X-band and 0.5 m^2 for S-band. For typical channel markers, with an RCS of 1.0 m^2 (X-band) and 0.1 m^2 (S-band) and height of 1 m, a detection range of 2.0 NM and 1.0 NM respectively.
d RCS for 10 m small vessel taken as 2.5 m^2 for X-band and 1.4 m^2 for S-band (taken as a distributed target).
e Reflectors are taken as point targets, vessels as complex targets and shorelines as distributed targets(typical values for a rocky shoreline, but are dependent on profile).
f Detection ranges experienced in practice will be affected by various factors, including atmospheric conditions (for example evaporation duct), target speed and aspect, target material and target structure. These and other factors may either enhance or degrade the target detection at all ranges. At ranges between the first detection and own ship, the radar return may be reduced or enhanced by signal multi-paths, which depend on factors such as antenna/target centroid height, target structure, sea state and radar frequency band.
g See Clause D.7.

NOTE 1 RCS values can vary by as much as 30 dB according to target characteristics and aspects, resulting in changes in detection range (see Annex D).
NOTE 2 Detection performance predictions for the range of first detection are derived from CARPET software calculations (CARPET: radar analysis software: Computer Aided Radar Performance Evaluation Tool).

the coast.

2.2 Tests on shore-based test sites

Although IEC62388 allows the test to be performed on a shore-based test site, other considerations are due for proper testing: the radar antenna is conducted with a nominal antenna height of 15 m, the test targets are observable by shipborne radar, and the waters around or near the test site present rough sea conditions (Sea State 2–5) in sufficient frequency. The minimum range is one of the performance requirements: the target must be able to be identified within 40 m (horizontally) of the antenna position. To install the antenna of the radar under a test height of 15 m above sea level, it is normally necessary to build a tower or similar structure on the test site. In view of the need to perform tests to confirm the value of minimum range, the radar should be installed as near to the coastline as possible, as such a location has an effect of reducing clutter originated from ground surface reflections.

Taking all these and additional conditions such as the frequency of rough sea occurrence (Sea State ≥3) and ease of access from NICT into consideration, a coastline in Niigata prefecture was selected for the test site survey. The coastline which was investigated extends about 100 km, from Nyuzen-town (Toyama pref.) to Nodate section of Joetsu-city (Niigata pref.), with the Oyashirazu coast (Itoigawa-city, Niigata pref.) at its central portion.

The survey did not make it possible to find the location (a possible site for performance tests) at which all required targets described in IEC62388 (see Table 2) could be observed at one time by radar. However, it became clear that several sections of the coastline did satisfy important aspects to be a candidate: sea state conditions, availability of target ships (regular liners that navigate nearby waters, lease of fishing boats from the fishermen's cooperative), and install ability of specific targets (e.g. buoys) off the coast. In view of these considerations, it was decided that the test site be constructed in the coastal section near the Arimagawa fishery harbor (Joetsu-city, Niigata pref.).

Figure 1 shows the external appearance of the radar performance test site constructed at Arimagawa (note: NICT was in charge of the selection and basic design of the test site, but the main agent for construction and management is MIC, the supervisory authority for implementing type approval test). The steel tower is designed to provide an appropriate height for the radars to be tested (15 m above sea level, when the radar antenna is installed at the top of the tower). In terms of system configuration, the shipborne radars could be classified into two groups: two-unit type (also referred to as Up Mast type: antenna, transmitter, and receiver share the same chassis) and three-unit type (also referred to as Down Mast type: the antenna and transmitter/receiver are mounted separately in multiple of chassis). For the test using the latter type, storage (a cubicle) is provided right below the steel tower for mounting the transmitter/receiver unit. The radar's display unit (indicators) is installed in the observation room, which allows the operator or the inspector of type approval test to conduct the test while monitoring sea conditions.

To conduct a test properly, a set of targets (reference targets) must be arranged in the designed locations. In water near this construction on the test site, two reference targets are installed: one at 40 m and the other at 1 NM distance from the radar (see Fig.2).

The target at 40 m (Fig.3) is a spatially fixed target with a Luneburg lens (RCS 10 m^2 for X-band) mounted on top of the pole made by FRP (Fiber-Reinforced Plastics) at a height of 3.5 m above sea level.

The target at 1 NM (Fig. 4) was first designed to be

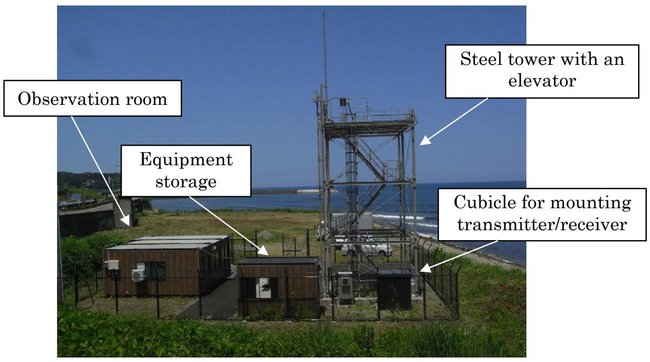


Fig. 1 Radar performance test site at Arimagawa

Fig. 3 Target installed at 40 m from the radar

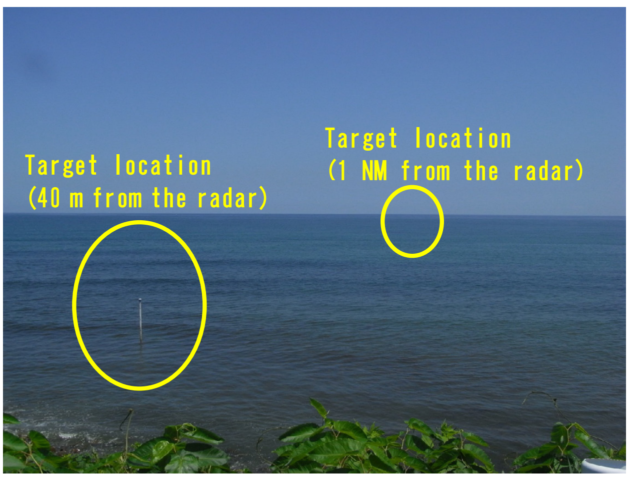


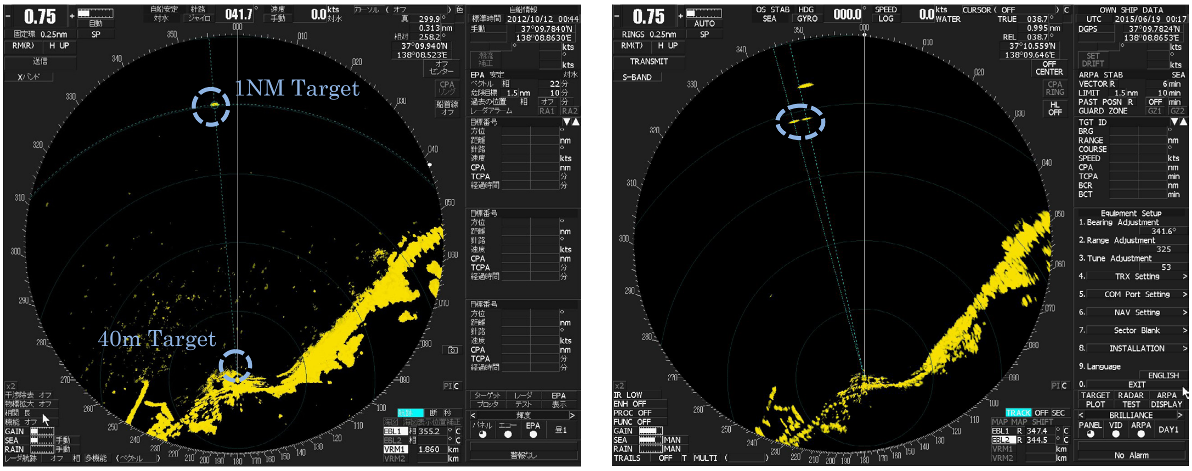
Fig. 2 Arimagawa radar test site (a view from the steel tower)

Fig. 4 Fixed target at 1 NM from the radar (a spar buoy)

positioned at a fixed point on the sea surface by mounting it on a floating spar buoy (a type of floating buoy with a long leg-like portion of its body extending into the sea. It has the merits of not using long chains, small drift from the designed position, and smaller tilting under the effect of waves and wind). However, because of the rough sea conditions in winter off the coastline of Arimagawa, many incidents occurred such as the loss of a Luneburg lens due to breakage of the fixing clasp or fracture of the pole. In addition, chains to fix the buoy require cost and time for maintenance. In reality, the test site is not stationed with personnel except for the duration of the test, making prompt attention virtually impossible in the case of an accident such as a breakage or loss of fixed targets. In view of these concerns, at present, the target is installed only during the period of running tests by means of fixing anchor, instead of maintaining fixing targets.

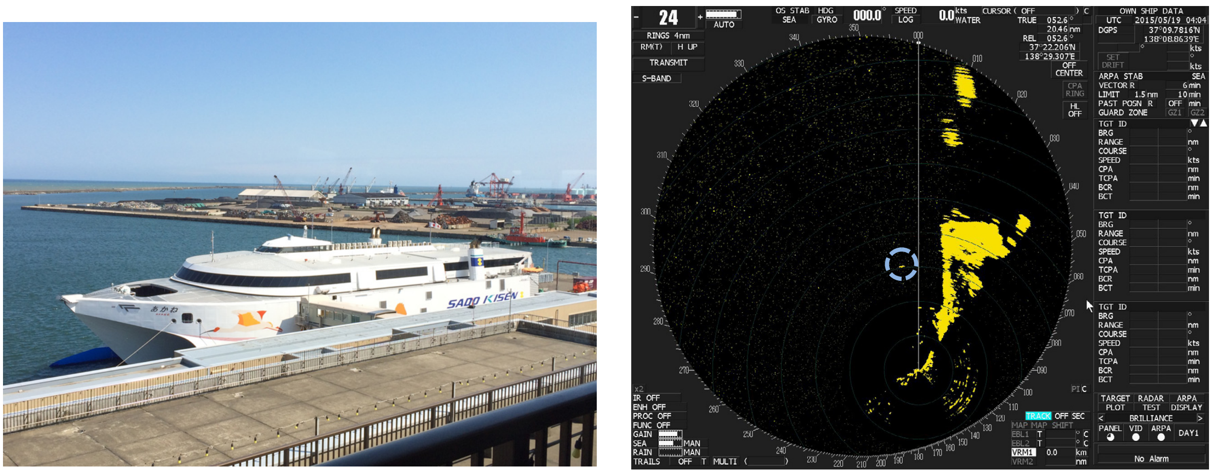
Fig. 5 Fixed target at 1 NM distance (left) and moveable target (right)

The reference targets need to be used even in rough sea conditions. So one of the remaining tasks is to develop reference targets that are more robust and highly resistant to rough hydrographic phenomena (free from breakage and



(Reference target) (Bearing discrimination test)

Fig. 6 Images observed from the radar mounted on top of the tower



(Ferry “Akane,” Sado Steam Ship Co., Ltd.) (Observed image of Akane: long-distance range discrimination)

Fig. 7 An example of target ship, and its observed image loss), as well as being easier to relocate.

Actual tests are conducted using a fixed reference target placed in a specific position on the sea, and a movable reference target. In the bearing discrimination test or the range discrimination test, the distance between two targets is measured at the moment their spots on the radar screen just begin to separate. For this purpose, a movable target that is a boat with a small engine and a Luneburg lens mounted on it (Fig.5, right) is navigated in bearing or range direction around the fixed target.

As an example, Fig.6 shows two radar images observed from the Arimagawa test site, one indicating an image of a reference target, the other indicating an image during a bearing discrimination test.

In detection performance tests, in addition to the movable target described above, various objects observable from the Arimagawa site are utilized, including the regular liner connecting Naoetsu and Sado Island (Fig.7 shows a ferry), fishing vessels based in Arimagawa harbor, and coastlines and quay walls with a known distance from the site. To confirm whether these objects can be used for reference purposes, we have prepared a method to evaluate RCS (Radar Cross Section) of the targets based on the levels of power received by reference radars with known performance, and the validity of the test was further examined in reference to the information presented in IEC62388 (e.g. Annex D: "Factors that influence target detection," and others).

To estimate RCS of the target, the video signal (the signal received and detected by a radar receiver) output from the reference radar (radar the performance of which is known) is recorded first, then the RCS are evaluated from the recorded signal and its fluctuation level (Fig.8 shows an example of a screen image of a prepared video signal recording system; vertical and horizontal axis respectively represent A scope (signal level vs. time) and B scope (distance vs. bearing)).

Concerning the test conducted in the Arimagawa site, sea clutter due to a well-kept linear swell, frequently occur at Arimagawa coastal waters, which is one factor making the decision on compliance with the standards difficult. The heaving sea produces long string-like images on the radar display, often making identification or discrimination of a specific target difficult (see Fig.9). Especially in range or bearing discrimination tests, clear separation between the two targets arranged in range or bearing directions must be confirmed in 8 scans (e.g. updates of screen image) out of 10, or 16 scans out of 20, but overlapping swell makes this process very difficult. A test item requires detection of a target that is positioned at or within the distance of 40 m from the radar, and the occurrence of a continuous swell between the land and the target (positioned 40 m off the beach) may often produce interference images, making land-target separation difficult. To avoid such interference, characteristics of the swell studied by observing them, and positioning of reference targets are designed to reduce the effect as much as possible. However, repeated tests and data evaluation in this test site have gradually revealed that

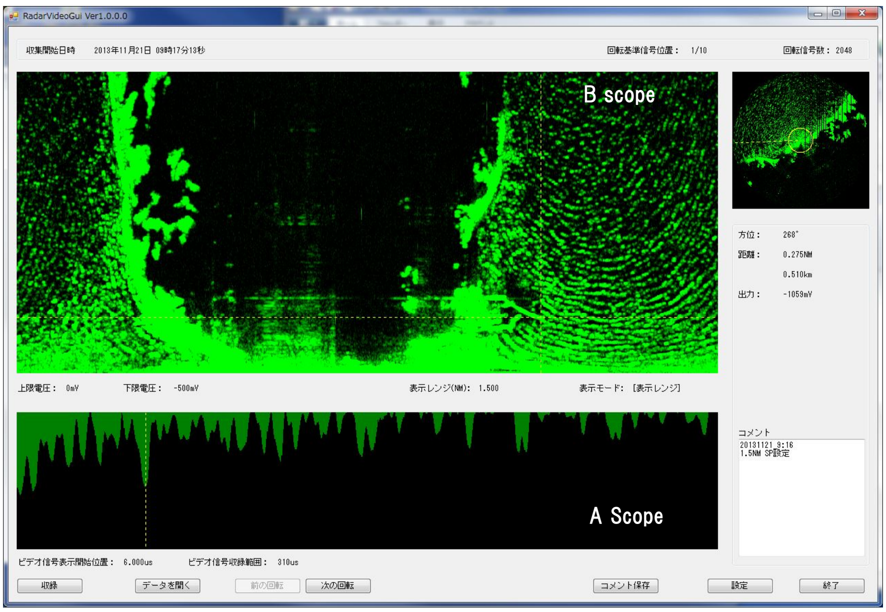


Fig. 8 Display of video signal (radar video signal recorder)

positional gaps exist between the initially predicted direction of the swell and positional arrangement of reference targets (the gap was especially significant for the fixed target positioned at 40 m from the radar). Thus, it has become clear that the positional design for installing reference targets needs reviewing. This review and improvement still remain as a future issue, because they require close consultation with the local fishery cooperative: as the adjacent waters of the Arimagawa test site are an important ground for grill net fishing, positioning of targets on the sea (especially the fixed targets) needs approval from the local fishery cooperative and reaching agreement may take time.

In the Arimagawa site, occurrence of a phenomenon, seemingly originating from the radio duct effect, is rarely observed — i.e. a target is detected as if it is located farther away than the line-of-sight distance[7]. A condition placed on evaluating target detection performance stipulates that the measurement be made in absence of the radio duct effect. Therefore, investigation must be made on the conditions leading to the occurrence of the radio duct effect, and the test method needs more study so that the effect can be removed from the measurement results as much as possible.

The target installed on the sea and currently in use is a radar reflector installed at the height of 3.5 m on a small boat (see Fig.5). This structure is somewhat unstable as it is top-heavy. This unstableness sometimes brings about obstacles to the test: larger fluctuation of the boat in rough sea gives larger variations of RCS. On the other hand, IEC62388 also includes specifications for a target detection performance test conducted in higher sea states. To address these conditions, we consider it is one of our important issues that we must resolve to develop the test method, construct facilities like reference targets, and prepare an environment that enables stable execution of the tests even in rough sea states.

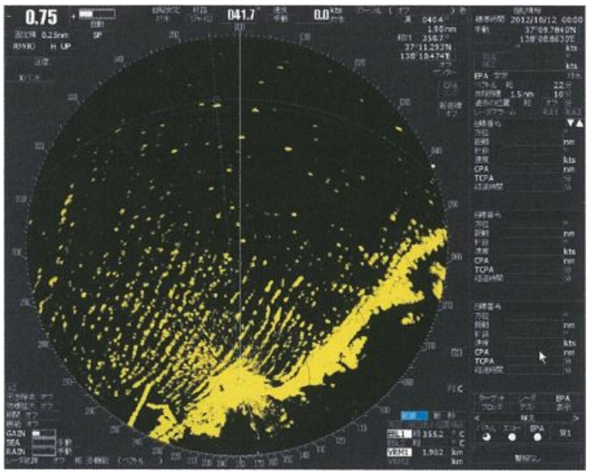


Fig. 9 Radar image of a swell in the waters near Arimagawa test site

2.3 Tests by radar installed on the ship

IEC62388 does not exclude the possibility of conducting a radar performance test at sea on a test ship (i.e. test with a radar installed on the ship). It is also apparent that the performance evaluation using radar installed on a ship is more acceptable from the users' point of view. Therefore, NICT has made a study on this test scheme and actually implemented it by installing the radar under test on an actual ship.

To determine appropriate waters for shipboard tests, a survey was made based on the basic criteria described in

(source: maps released by Geographical Information Authority of Japan (maps.gsi.go.jp))

(Test route 1) Noto peninsula route　　(Test route 2) Toyama Bay route

Fig. 10 Test waters and navigation routes for shipboard tests

2.1, and finally Toyama bay and coastal waters along Noto peninsula were selected. These waters also have additional merits: easy access from the Arimagawa test site, and presence of targets that meet most of the conditions described in IEC62388. The test waters and navigation routes (for test ship navigation) were determined taking the possible targets into consideration. The results are shown in Fig.10.

The radar under test must be positioned at a height 15 m above sea level. Therefore, small ship-like fishing vessels may prove unfit for installing a structure of such height. Because of that, leasing possibilities of larger ships (499-ton class or larger), capable of mounting the antenna of given height, were investigated. Figure 11 shows photographs of a ship that cooperated with us while we investigated the test routes and so on. This ship has a total tonnage of 745 and the height of its second radar position meets the requirement of 15 m above sea level.

The performance tests using shipboard equipment is based on the measurements taken against real-world objectives (with similar characteristics to those listed in Table 2) that are located or navigating in the waters (buoys, ships, islands, coastal lines, and others). Based on the results of investigation, two routes were determined. Test route 1 assumes two major measurements – Ooshima (approx. 62 m above sea level) of Nanatsu-jima and Aramikojima (approx. 59 m above sea level) from the distance of 20 NM. Route 2 assumes one major measurement – Abugashima (approx. 4.5 m above sea level) from the distance of 8 to 6 NM. Other targets listed in Table 2 were confirmed to be available — e.g. buoys arranged in adjacent waters of Nanao and Toyama harbor, and the ships navigating in the nearby waters.

The major test item to be conducted while navigating test route 1 is long-distance range discrimination tests that observe “Shorelines rising to 60 m from the distance of 20 NM using X-band and S-band radar.” Examples of the views of the targets and their image on radar screen are shown in Fig.12 and Fig.13.

The major test item to be conducted while navigating test route 2 is planned to be “Shorelines rising to 6 m from the distance of 8 NM using X-band and S-band radar” or “Shorelines rising to 3 m from the distance of 6 NM using X-band and S-band radar.” The route is also designed to address the following measurement objectives against the buoys arranged in the adjacent waters of Toyama harbor and the navigation buoys arranged in Nanao harbor: Detection of “Typical navigation buoy from the distance of 4.6 NM (X-band radar)/3 NM (S-band radar),” “Channel makers from the distance of 2 NM (X-band radar)/1 NM (S-band radar),” or “Navigation buoy with corner reflector from the distance of 4.9 NM (X-band radar)/3.6 NM(S-band radar).” Examples of the views of these targets and their images on radar screen are shown in Fig.14 and Fig.15.

The navigation buoys currently in use in Japan often have larger RCS than those buoys specified by IEC62388 — the RCS values of a navigation buoy with a corner reflector described in the Annex of IEC62388 are 10m^2 for X-band radar and 1.0 m^2 for S-band radar. This makes many of the buoys currently used in Japan unfit for use as reference targets. To cope with this situation, the following two approaches may be considered: 1) Prepare a new target for a test that meets IEC62388 requirements, 2) Measure the detailed shape and RCS of actual buoys, and using the results, carry out a calculation with the radar analysis software CARPET (Computer Aided Radar Performance Evaluation Tool)[8] introduced in IEC62388 or similar software.

The test using shipboard equipment provides a more realistic environment — e.g. rolls and pitch of the ship are taken into account — and the results will be more practical for the users. On the other hand, this approach will take more time, because measurements are made on the way to the specific point on the water. Furthermore, the size, construction and structure (structural elements, such as the mast, may reflect radio waves) of the ship to use, in addition to the weather conditions when the test is conducted, may affect the test results (affect the images of the target and sea clutter displayed on the radar screen). It is clearly advantageous to use the same test ship all the time (possession of a ship), but other conditions still need to be met to conduct the test under the same set of conditions — for example, the system that enables the ship to leave a port at the arrival of favorable conditions without delay. This test inherently depends largely on the skill and experience of the type approval test inspector. With all things considered, it is not an easy task to conduct a test under completely the same conditions (conduct completely bias-free test).

3 Concluding remarks

IEC62388-based radar performance tests are, as might be expected, conducted by many overseas type approval test bodies as well. However, the trend in recent years has

Fig. 11 The ship used in the test target investigation (external view and inside the deck (a scene during investigation))

Fig. 12 Ooshima (left: 62 m ASL) and Aramikojima (right: 59 m ASL)

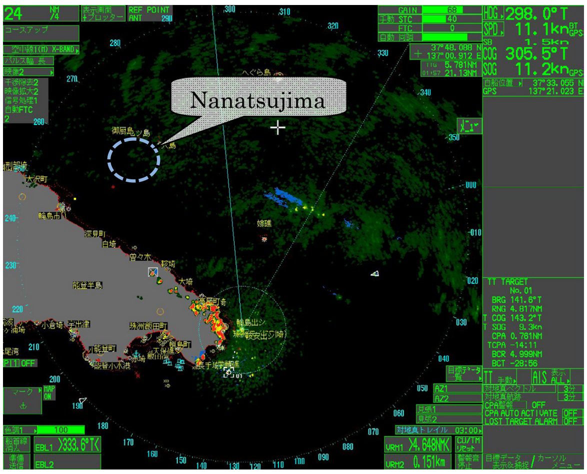


Fig. 13 Radar image of Nanatsujima (observed from the distance of 20 NM)

been toward ground-based tests (observation of test targets from a steel tower installed on a coastline), and only a few still conduct shipboard tests (the radar under test is mounted on a test ship).

The shipborne radar is radio equipment designed for operation onboard a ship under various actual situations — rolling and pitching of a ship, fluctuation of radio wave, etc. As described previously, IEC62388 was revised to include more consideration to the tests under actual operating conditions (importance of users' viewpoints), which makes a convincing case for our belief that shipboard testing should remain as a basic mode of radar tests.

Therefore, the results obtained from shore-based tests must reflect various situations experienced by shipboard radar tests as much as possible, to prevent the occurrence of discrepancies between the two modes both in results and evaluation. It is one of our issues to develop the methods and environment for this purpose, where application of the experience and data accumulated through many shipboard radar tests and investigations can play an important role to improve shore-based performance tests.

From the viewpoint of conducting the test under the same conditions and excluding bias from the test results as far as possible, a simulation technique unaffected by weather might be an effective tool. We consider it necessary

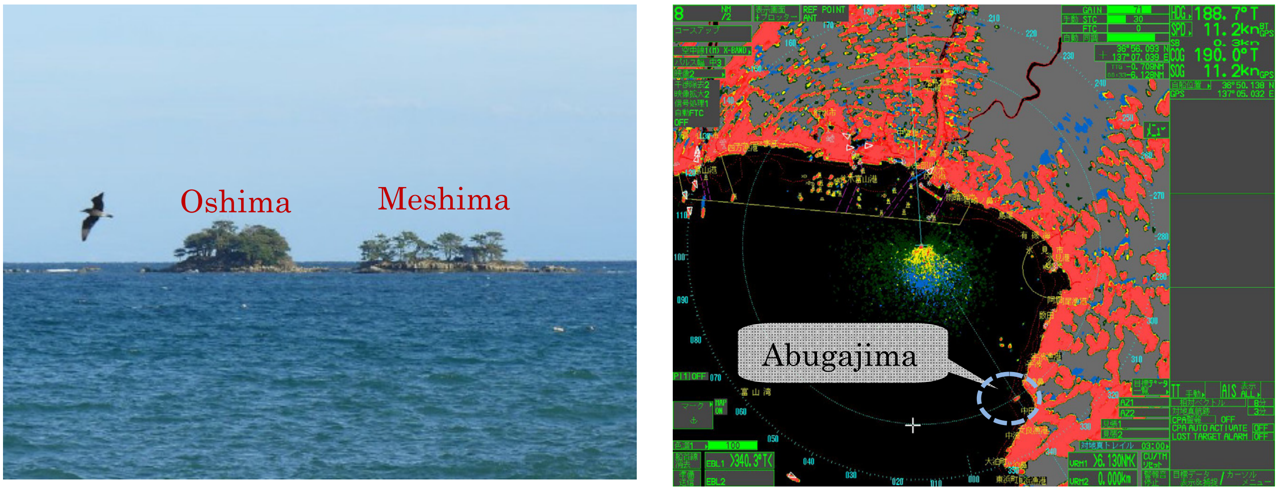


Fig. 14 A view of Abugajima, and a radar image of Abugajima and Toyama Bay (captured from a distance of 6 NM)

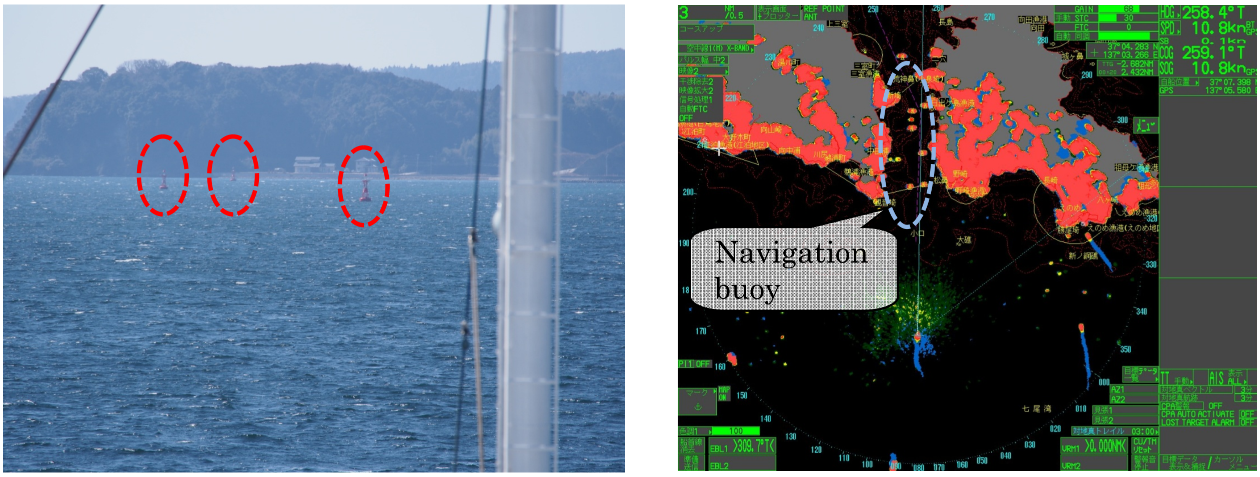


Fig. 15 Navigation buoys arranged on Nanao Minami Bay, and a radar image of them

to investigate the possibility of using such a technique for performance test by simulation, e.g. utilizing rapidly developing technologies such as an arbitrary waveform generator.

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