Development of Mid-Mast TACAN Radio Beacon Antennas for Ships

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Abstract

NEC Corporation develops and manufactures a variety of key infrastructure that contribute to the security, safety, and efficiency of aviation, such as systems for air traffic control, radar, navigation, and landing guides. One is the tactical air navigation (TACAN) system, which is a radio beacon system that provides aircraft with distance and bearing information. The TACAN system is not only installed on land but also on the Japan Maritime Self Defense Forces ships carrying helicopters, etc. It has been considered that the optimum positioning of the antenna of a ship-borne TACAN system is the top of the mast because its openness is suitable for helicopters in all directions. However, NEC Corporation has developed the world's first TACAN system that can provide omnidirectional service even when it is installed in the middle of the mast, and this paper will introduce its details.

Keywords

TACAN, navigation aid system, antenna, destroyer, mid-mast, bearing error, flight safety

1. Introduction

For safety flights, accurate identification of the aircraft's position during flight is required. Radio equipment for this purpose includes a tactical air navigation (TACAN) system, which is a radio beacon system that obtains necessary information from the radio waves transmitted from land, the distance measuring equipment (DME), the very high frequency omnidirectional range (VOR) system and the Michibiki satellite-based augmentation service (MSAS) that augments the information from the global positioning system (GPS) with radio waves from the quasi-zenith satellite. NEC designs and manufactures a TACAN system for providing aircraft with the distance and bearing information as well as a DME system for providing aircraft with the distance information and then supplies them to major Japanese organizations. Particularly, the TACAN systems are not only installed on land but also installed on Aegis-equipped destroyer, and thus becoming key infrastructure for ensuring safe flights for ship-based aircraft (**Fig. 1**). Even though GPS and other satellite navigation systems have become mainstream, there is still a need for the TACAN system, which allows the pilot to receive radio signals from his mother ship to know the distance and bearing from them.

Conventional antennas of shipborne TACAN systems are installed on the top of masts where they can be seen

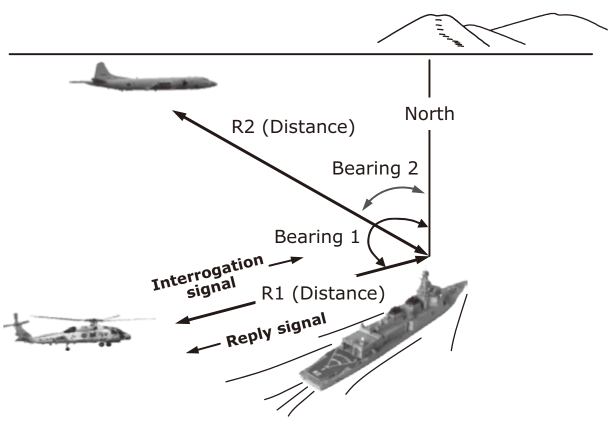

Fig. 1 Conceptual diagram of a shipboard TACAN system operation.

because of the need for omnidirectional service. This is because the higher antenna enhances its coverage. More recently, however, to improve the defense capability against increasingly sophisticated threats, there has been a growing need to install antennas at the top of masts to detect such threats.

Based on these needs as well as experience in the integration of the TACAN system, NEC has developed the world's first shipborne TACAN antenna that can provide the same performance as a conventional one even when it is installed in the middle of the mast. This paper will introduce NEC's newly developed antenna.

2. Development Concept

The following concepts were used in the development of the new TACAN antenna to meet the needs of users while maintaining performance.

(1) To improve aircraft safety
(2) To be compatible with various mast diameters and inclinations at mid-mast
(3) To consider the radar cross section (RCS)
(4) To shorten the maintenance time

2.1 Improved aircraft safety

As conventional TACAN antennas are disk-shaped and installed on the top of the mast as shown in **Fig. 2**, a lightning rod installed near the antenna to minimize the effects of lightning strikes has been necessary. However, when a lightning rod is installed near the antenna, the bearing accuracy of TACAN is degraded. Also, when the installation location of the TACAN antenna is lowered from the top to the middle of the mast, the radio waves will be reflected by the mast and the bearing accuracy will be degraded. To deal with these issues, NEC has developed a new mast-penetrating TACAN antenna that posits the antenna around the mast. This eliminates any influence of the lightning rods and masts and also improves the safety of the aircraft.

2.2 Compatibility with various mast diameters and inclinations at mid-mast

To be able to install a TACAN antenna in the middle of a mast, the area through which the mast passes must be hollow or doughnut-shaped instead of the conventional disk-shaped antenna. If the whole TACAN system were to be redesigned, it would be possible to adopt the cylindrical active phased array design in which the transmitter-receiver and antenna are arranged in a circle. In this case, however, NEC studied the possibility of replacing only the antennas while keeping the conventional transmitters and receivers installed in the ship's equipment room.

2.2.1 Change of modulation method

In a conventional TACAN antenna, the dipole element for transmission/reception is installed on a disk-shaped reflector plate, the switching modules for 15 Hz are placed around the dipole element, and the switching modules for 135 Hz are arranged in a circle around them (**Fig. 3**). The switching modules on the reflector plate modify the signal emitted from the dipole element with spatial amplitude modulation to generate the TACAN signal required to measure the bearing. Although this method is very efficient thanks to the direct radiation of the transmitter output from the dipole element, this structure cannot be passed through the mast because of the presence of the dipole element in the center.

Meanwhile, the ground-based TACAN antenna produced by NEC can be shaped like a doughnut, because the antenna elements are arranged in a circular shape. As a result, NEC examined the electric characteristics and structure based on that shape.

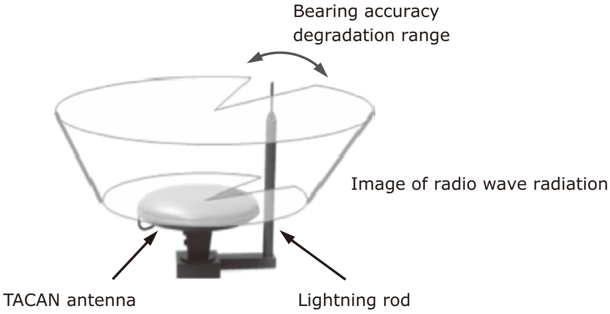

Fig. 2 Effect of conventional TACAN antennas and lightning rods on bearing accuracy.

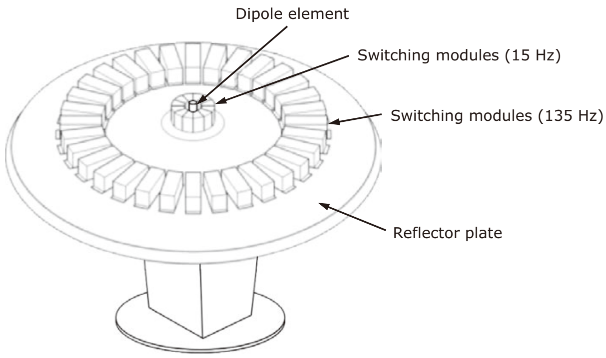

Fig. 3 Structure of conventional antennas.

The ground-based TACAN antenna is composed of a distributor and modulator that radiate amplitude-modulated signals from the 36 antenna elements arranged in a circle. The pattern of TACAN's horizontal radiation is characterized by the fact that the sum of the two electric fields located at 180 degrees from each other is constant and that an increase in one electric field causes a decrease in the other electric field. By using this radiation characteristic so that the output from the modulator is divided into two parts to control the amplification modulation in the opposite phase of the other, it is possible to input a signal of constant amplitude. This is because the power of the input signal can be output with a low loss. By supplying high-frequency signals whose amplitudes are 180 degrees out of phase with each other to antenna elements that are offset by 180 degrees from each other, a low loss is achieved.

2.2.2 Adoption of split structures

The split structure of the antenna was developed by taking into consideration how the mounting on the middle part of the mast could be installed, replaced if a failure occurred, or removed for periodical repairs. The use of the same modulation method as the ground-based TACAN antenna was adopted, which required a constant phase of radio wave from the input to the 36 antenna elements. As described earlier, to supply the outputs of two lines from the modulator to two antenna elements that are 180 degrees opposite each other, the 18 antenna elements of each of the two radiation sections in the same phase must be connected. For this purpose, NEC developed a phase-controlled cable with multi-port coaxial connectors and designed the system so that several coaxial cables between the radiation sections can be attached or detached at the same time.

2.2.3 Directivity on vertical planes

With conventional antennas, the top of the beam with directivity on vertical planes is oriented at an elevation angle of +30 degrees by the effect of the reflector plate. With the new antenna, the amplitude of an elevation angle at 0 degrees is enhanced to improve the service for aircraft at distant low altitudes. Moreover, by reducing radiation at elevation angles of zero degrees or less, the effect of reflected waves from the sea surface on bearing accuracy is suppressed. To improve the directivity, repeated simulations and prototyping were carried out, taking into account the tilt of the antenna so that the vertical plane's directivity eventually falls within the target performance range. As a result of trial experiments, a TACAN antenna with a two-block construction and capable of being installed in the middle of the mast was prototyped (**Fig. 4**).

2.2.4 Diameter of the mast hole

The diameter of the mast hole must be as large as possible, because the cross-sectional shape and inclination of masts vary between ships and the antenna should be compatible with as many ships as possible. Therefore, the antenna elements arranged on the circumference were developed to be less than half the size of those in a conventional antenna. Also, the placement of the modulator made it possible to meet the

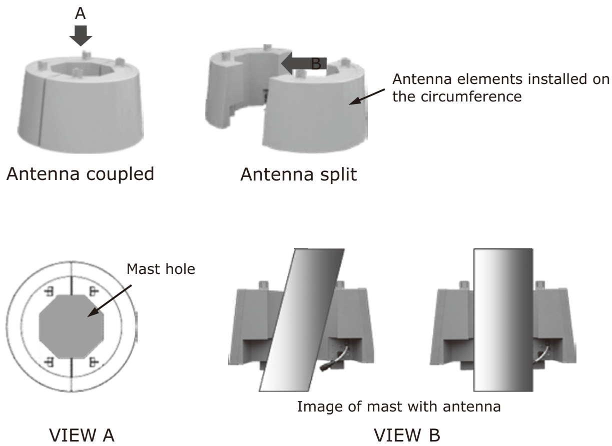

Fig. 4 Structure of antenna.

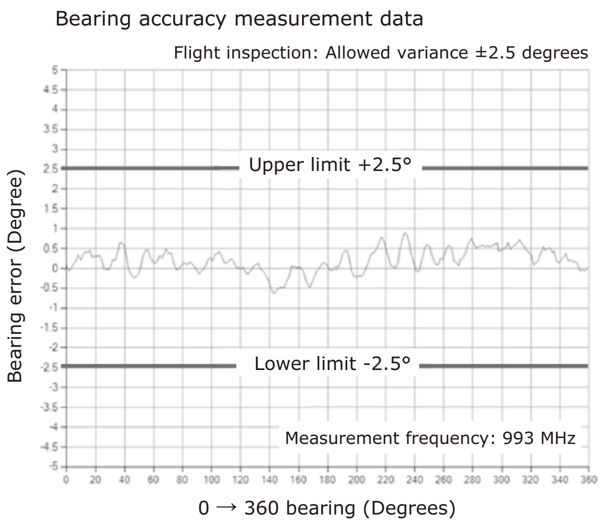

Fig. 5 Measurement data of antenna with small bearing error.

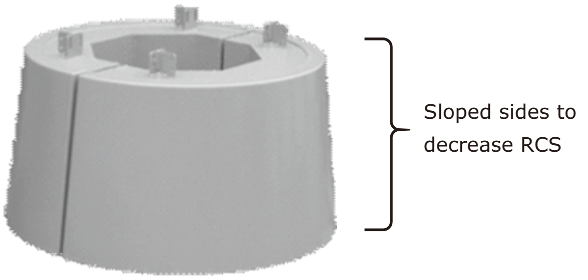

Fig. 6 Shape of antenna to decrease RCS.

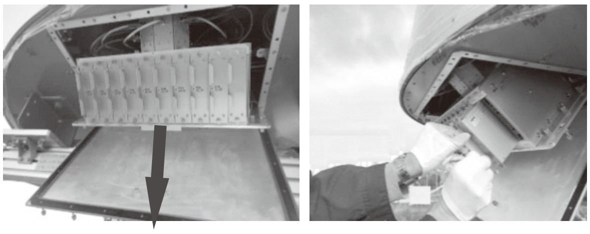

Fig. 7 Shortened maintenance time when replacing modulators.

performance requirements for the TACAN system even when the thickness of the antenna section is decreased.

2.2.5 Confirmation of bearing accuracy

The pattern measurement was evaluated to confirm that the final design meets the requirements for the TACAN antenna. A practical assessment of it as a TACAN system was also conducted and the fact that the bearing error is small in all directions was confirmed (**Fig. 5**).

2.3 Consideration of the Radar cross section

TACAN antennas for ships need to have a small radar cross section (RCS) for electromagnetic waves to improve survivability against threats.

The TACAN antenna shown here has sloped sides to decrease the RCS by reflecting horizontal radar waves so the move upward (**Fig. 6**). With the sloped side panels, the antenna looks more like an angel cake pan than a doughnut.

2.4 Shortened maintenance time

As described earlier, the TACAN antenna has a modulator for amplitude modulation of the transmitted radio waves. The modulator is in a position accessible from below the antenna to help make maintenance and servicing easier. It has a plug-in connection to eliminate the need to attach and detach cables and to shorten the maintenance time (**Fig. 7**). The ship's antenna is installed in the middle of the mast and is a high, narrow work area, so it is designed with the safety and workability of the maintenance personnel in mind.

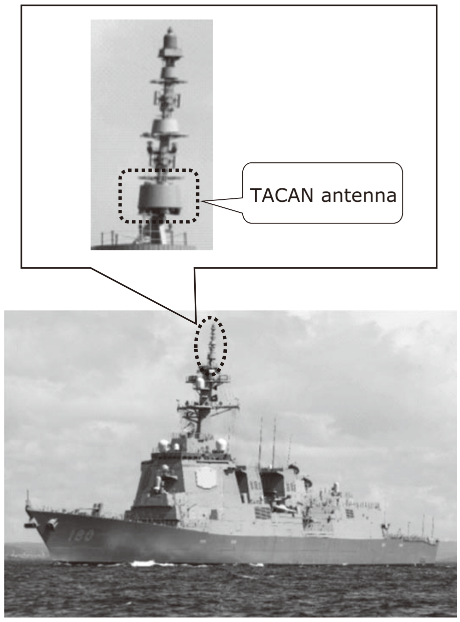

Fig. 8 Case of installation (HAGURO).

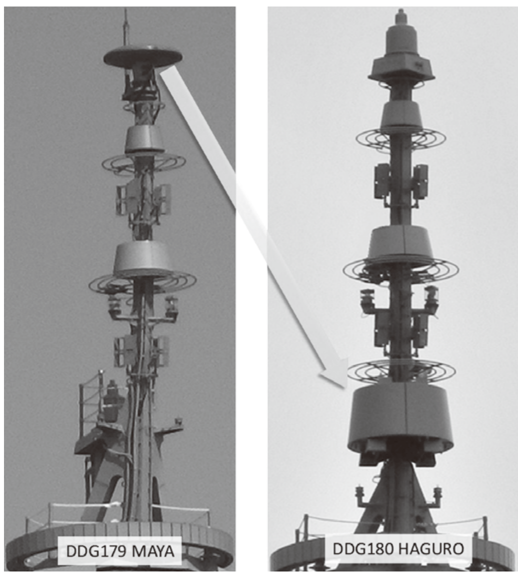

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Fig. 9 Comparison of installation location of conventional/new antennas.

Table Comparison of functionality between conventional/ new antennas.

Item	Conventional antenna	New antenna	Evaluation
Functions/ performances	Bearing error caused by lightning rod	Lowered bearing error	Improved
Aircraft safety	Bearing error caused by lightning rod	Lowered bearing error	Improved
Environmental resistance	Concerns about lightning damage	Lightning avoidance	Improved
Contribution to ship survivability	On mast top	Other antennas installable on mast top	Improved
Maintenance/rigging	Dangerous work	Safe, efficient work	Excellent improved

3. Cases of Actual Installations

A TACAN antenna was installed on the JS Haguro, the JMSDF's latest Aegis-equipped destroyer (**Fig. 8**). The TACAN system on the Haguro was put into commission in March 2021 after having passed operational tests on the sea.

The TACAN antenna developed by NEC was also installed on the JS Aki, a JMSDF ocean surveillance ship recommissioned 30 years after leaving the active fleet. With previous ocean surveillance ships, the satellite antenna was prioritized and installed on the top of the mast with the TACAN antenna installed next to the satellite antenna. As a result, the bearing error was not within the acceptable range because of the blind area created by the mast of the satellite antenna and reflected radio waves from them. With Aki, the TACAN antenna is installed in the middle of the satellite antenna mast, and the bearing error was well within the acceptable range.

The TACAN antenna was also installed as part of the composite communication antennas of the 30FFM Kumano, a new frigate presently under construction.

Fig. 9 shows a comparative example of the installation location between the previous and new antennas, and the **Table** shows a functional comparison.

4. Conclusion

The mid-mast configuration of the TACAN antenna for ships has greatly improved the bearing accuracy of the TACAN antennas as well as the ease of maintenance and servicing. It is expected that, in the future, TACAN antennas for ships will be the mid-mast type. Since no TACAN antenna of this type is currently being used anywhere in the world, NEC will advance the business by also considering overseas deployment.

In closing, the authors would like to express deep gratitude toward the Japanese Acquisition, Technology & Logistics Agency for their kind guidance and support for this development project.

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