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**□** ARM **□** ENG **□** PAP **□** Input

* ENAV **□** VTS **** Information

Agenda item [[2]](#footnote-2) 5.1.10

Technical Domain / Task Number 2 …………………………………

Author(s) / Submitter(s) China Maritime Safety Administration

**Construction and Testing of VDES Project in North China Sea the Navigation Guarantee Center of North China Sea**

1. **Background**

VDES, as an upgrade system of AIS, not only provides ship-collision avoidance function, but also provides data communication function. From 2015 to now, China has carried out a series of exploratory studies and made some achievements. The VDES system demonstration and validation project implemented in 2016, has completed the physical radio frequency channel test for applications of AIS, ASM and VDE, realized modulation and demodulation algorithm and validate its effectiveness, and developed VDES base station, ship-borne prototype and related software.

On this basis, the China Maritime Safety Administration (MSA) has constructed a VDES communication network consisting of VDES shore-based station, VDES system management center and VDES ship-borne equipment in the Bohai Bay region from 2018 to 2019. The VDES communication system has been tested using the shore-based station and the ship-borne equipment.

1. **Project construction**

For the construction project of VDES in North China Sea, VDES shore-based stations were built in Tianjin port, Caofeidian port and Huanghua port in Bohai Bay. The stations are controlled by the VDES shore-based management center through optical fiber network. The shore-based stations can communicate with the ship-borne VDES equipment. The project realizes the communication on AIS, ASM and VDE channels between ship-borne equipment and shore-based station, which can be used as a mean to realize the applications of maritime safety information, navigation mark and electronic chart.

In VDES system, the front-end wireless data exchange network is composed of VDES ship-borne prototype and VDES shore-based prototype. The hardware system architecture is shown in the figure below:



Figure - Hardware system architecture of VDES system

VDES hardware platform is mainly composed of transceiver switch, TDMA transmitter supporting AIS, ASM and VDE, TDMA receiver supporting AIS, ASM and VDE, GNSS receiver and controller. The VDES hardware platform configured with VDES base station controller form VDES shore-based station equipment.

Shore-based software system consists of base station management software and information broadcasting software.

The base station management software follows the overall system architecture, is divided into service layer, interface layer and application layer. The system functions include equipment management and monitoring management. Equipment management includes equipment control management, broadcast control management and antenna control; monitoring management includes radio monitoring and equipment performance monitoring. The software architecture is shown in the figure below.



Figure - Architecture of base station management software

The system functions of information dissemination software include dynamic broadcast of AIDS to navigation, chart correction broadcast, hydrometeorological broadcast and statistical analysis. Its architecture is as follows



Figure - Information dissemination software architecture

The application software of ship-borne VDES mainly includes two parts: electronic chart module and equipment management module. The functions of electronic chart module include basic information display, S57 chart display, MSP information display, channel monitoring, time display, data and Chinese display; the functions of equipment management module include chart management and update, MSP information management, channel management, equipment configuration, data query and broadcast information setting.

1. **System tests**

The test involves three base stations constructed in the project, one VDES base station temporarily built in Tianjin port, one VDES management center and VDES shipboard equipment.

* 1. **Data transmission test**
     1. **INTRODUCTION**

This test mainly aimed to test the packet error rate (PER) and data transmission time between base stations and the ship-borne terminals within the coverage range.

* + 1. **TEST PROCESS**

The test points selected for the fixed-point test are all land-based points, which were distributed in the range of 20-40 km around each base station. During the test, VDES ship-borne equipment was set up at the fixed positions. Each VDES base station broadcasted ASM and VDE signals, and VDES ship-borne equipment received signal data at fixed positions. The signal was analyzed and displayed through the application software of shipboard equipment. The number of received and transmitted packets was recorded and the PER is calculated. At the same time, the VDES ship-borne equipment sent ASM and VDE signals with the same steps, which were received by the base stations to evaluate the communication effect of the terminal transmitting base stations. The distribution of test points is shown in the following figure:



Distribution of VDES Test Points in Huanghua Port

Distribution of VDES Test Points in Caofeidian Port

Distribution of VDES Test Points in Tianjin Port and Tianjin Communications Center

Figure 4 Distribution of VDES test points

* + 1. **TEST RESULTS AND ANALYSIS**

Comprehensive comparison of PER test data (note, "-" means that the receiving end of this test did not received a valid packet)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Base station and test point | Test distance | Test packet loss rate statistics (sorted by distance) | | | | | | | |
| ASM | | VDE-25kHz | | VDE-50kHz | | VDE-100kHz | |
| Base station → ship-borne | Ship-borne→ base station | Base station → ship-borne | Ship-borne → base station | Base station → ship-borne | Ship-borne → base station | Base station → ship-borne | Ship-borne → base station |
| Caofeidian base station - southwest of free trade zone | 19.6km | 34.84% | 78.27% | - | - | - | - | - | - |
| 20km southwest of Huanghua base station | 20 km | 4.68% | 11.35% | 5.41% | 26.07% | 0.95% | 15.70% | 7.72% | 41.35% |
| Tianjin communication center base station - Textile service area | 21.3 km | 5.76% | 18.60% | 11.28% | - | 74.10% | - | - | - |
| Caofeidian base station - Free Trade Zone | 21.6 km | - | - | - | - | - | - | - | - |
| Dongtui base station - Textile service area | 23.3 km | 3.33% | 43.33% | 1.47% | 25.39% | 1.14% | 49.08% | 1.87% | 36.31% |
| Caofeidian base station -Jidong Oilfield | 26 km | 4.25% | - | 8.91% | - | 32.72% | - | 79.47% | - |
| Tianjin communication center base station - Dashentang South | 29.7 km | 5.63% | - | 9.75% | 94.62% | 15.68% | - | 16.39% | 95.94% |
| 30km southwest of Huanghua base station | 30 km | 4.78% | 12.27% | 2.75% | 98.43% | 1.71% | 97.42% | 33.64% | 99.37% |
| Dongtui base station - South Port | 30.3 km | 5% | 25% | 5.31% | 27.78% | 3.81% | 38.40% | 4.30% | 15.90% |
| Caofeidian base station - Caofeidian East toll station | 31.3 km | 7.78% | 39% | 1.63% | - | 1.45% | - | 1.63% | - |
| Tianjin communication center base station - South Port | 32.3 km | 4% | 23.33% | 97.60% | - | 99.86% | - | 99.16% | - |
| 33Km southeast of Huanghua base station | 33 km | 6.75% | 97.70% | 98.90% | - | 99.25% | - | 97.68% | - |
| 33km northwest of Huanghua base station | 33 km | 13.39% | - | 61.59% | - | 30.72% | - | 41.97% | - |
| 38km southwest of Huanghua base station | 38.3 km | 43.17% | - | 10.15% | - | 16.47% | - | 4.47% | - |
| Caofeidian base station - Bodhi Island | 38.4 km | 7.60% | 54.09% | 1.86% | - | 1.33% | - | 1.46% | - |
| 43km south of Huanghua base station | 43 km | 6.13% | - | - | - | - | - | - | - |

According to the test results and data analysis, it can be seen that:

The effective transmission distance of ASM is farther than that of VDE when there is no obvious electromagnetic interference around the test site, the shielding of radio transmission path is small and the PER is relatively stable. And at the same distance, ASM has a lower PER than VDE.

In addition, under the same test conditions, ASM transmission stability is significantly higher than VDE in the presence of environmental interference or path obstruction. Under this condition, ASM has the best performance, followed by the VDE at 25kHz bandwidth and the VDE at 50kHz bandwidth. While the VDE at 100kHz bandwidth has low anti-interference ability, which is most susceptible.

Overall, under the same test conditions, regardless of the interference factors, each mode are reflected that the farther away from the base station, the higher the receiving PER.

Analysis of transmission rate of VDE channel

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Channel** | **Test time** | **Transmission path** | **Data length** | **Transmission duration** | **Rate** |
| 1 | VDE25k | 23:12 | ship→shore | 24064Byte | 38s | 5066bps |
| 2 | VDE50k | 22:25 | shore→ship | 128512Byte | 93s | 11054bps |
| 3 | VDE100k | 22:39 | shore→ship | 197632 Byte | 73s | 21658bps |

The actual data transmission rates in three bandwidth modes of VDE channel have been tested. When the transmission distance is 24 km, the test results show that the effective transmission rate is 5.07 kbps in 25kHz bandwidth, 11.05kbps in 50kHz bandwidth and 21.66kbps in 100kHz bandwidth.

* 1. **Voyage test**
     1. **INTRODUCTION**

The voyage test mainly aimed to test the functions and performance of VDES system in different distances and states. During the test, the VDES shore station and the ship station sent data and recorded the receiving situation to calculate PER, so as to verify the partial functions and performance of VDES ship and shore terminal equipment under the actual working conditions, check the working stability of the VDES ship and shore terminal equipment, and calculate the communication distance limit between the VDES ship station and shore station under the actual working conditions.

* + 1. **TEST PLAN**

During the voyage test, the VDES shore station was temporarily deployed in Tianjin VTS traffic control center, and the VHF antenna was temporarily fixed on the tower on the roof of the VTS traffic control center, and then connected the shore end test software with Dalian management center through the private network. At the same time, the VDES ship station was deployed in the cockpit of Haixun 152 ship, and the VHF antenna was fixed on the deck above the cockpit. Therefore, VDES ship station can be directly connected with the ship end test software through the network cable, and at the same time, it can be connected with the sensor equipment on board through the serial port to obtain the data of compass and log. All data records of VDES shore station and ship station are stored in the database of test computer. The route of Haixun 152 ship was the operation route for the replacement of aids to navigation along the channel of Tianjin port. The distance between the farthest buoy and VTS traffic control center is 14.4nm.



Figure 5 deployment location of shore station equipment

Figure 6 VHF antenna of base station (altitude: About 70m)

VTS control center

Base station VHF antenna

* + 1. **Test message design**

In order to test the transmission and reception of different types of messages, the messages sent by the ship station and shore station were designed before the test, so that the transmission effect of different types of messages under the same environment can be tested.

(1) AIS message design:

No separate test message is designed on the AIS channel. After using the test tool to configure the corresponding parameters for the participating VDES base stations and berths, according to the ITU\_1371 standard, the VDES equipment would automatically broadcast static messages, where the base station sends MSG4 messages with a sending frequency of send once every 10 seconds; the ship station sends MSG1/3/5 messages, and the sending frequency changes along the ship speed.

ASM message design: two kinds of messages are designed for ASM channel, broadcast message and addressed message. The specific content is as follows.

* Broadcast message: The message uses the Message 2 format specified in IALA G1139, and the test software encapsulates the ASM broadcast message 2 to be sent. The sending interval is 1 minute, and the encoding methods are respectively no encoding (Link ID1) and 3/4 encoding (Link ID5), the transmission channel is alternate on channel A/B, the payload data content is the current transmission time and the transmission sequence number. The length of the transmission message is 1 time slot, that is, 512 bits;
* Addressed message: The message uses the Message 4 format specified in IALA G1139. The test software encapsulates the ASM 4 addressed message to be sent. The sending interval is 18 seconds. The encoding methods are respectively no encoding (Link ID1) and 3/4 encoding ( Link ID5), the transmission channel is alternate on channel A/B, the payload data content is the current transmission time and the transmission sequence number. The length of the transmission message is 1 time slot, that is, 512 bits.

(2) VDE messages design: two kinds of messages are designed for VDE channels, broadcast message and addressed message, for testing. The specific content is as follows.

* Broadcast messages: No separate test message is designed on the VDE channel;
* Addressed messages: In the design of addressed messages, there are three kinds of VDE channels, 25kHz, 50kHz and 100kHz, each bandwidth has three modulation modes, pi/4 QPSK, 8PSK and 16QAM. The test software has designed 9 test messages, that is, ID11~ 19. The test messages are sent in cycles in sequence, with a sending interval of 18 seconds, the payload data content is the current sending time and the sending sequence number. The length of the sending message is 1 time slot.
  + 1. **MESSAGE INTERACTION PROCESS**

(1) Broadcast process

* AIS broadcast test process design: After the VDES device is powered on and synchronization with GPS is completed, the static information is broadcasted automatically, in which the shore station sends MSG4 messages with a frequency of 10 seconds, and the ship station sends MSG1/3/5 messages with a frequency varying along the speed of the ship. This process is not controlled by the test software;
* ASM broadcast test process design: The test software controls VDES base station and ship station equipment to automatically generate Link ID=1 and 5 test messages respectively, send circularly according to the alternate mode of A/B channel, the sending interval is 1 minute. That is, the test message which Link ID is 1 and 5 are sent in turn at intervals of 1 minute, until the test software is closed;
* VDE broadcast test process design: After the VDES base station device is powered on and synchronization with GPS is completed, the bulletin board data will be sent on time slots 0, 6, 12 starting every minute. This process is not controlled by the test software.

(2) Addressing process

The addressing tests of shore stations start automatically on the hour of Beijing time;

The addressing test of ship station is started manually, that is, a set of addressing tests is started every click.

A set of tests sends a total of 100 packets of test messages. The sending order is alternating between ASM and VDE channels and the sending interval is 18 seconds

According to the design results of ASM and VDE messages, the order of sending packets in a test cycle is: Link ID1»11»5»12»1»13»5»14»1»15»5»16»1»17»5»18»1»19. Loop through until 100 packets are sent.

* + 1. **TEST PROCESS**

(1) Before sailing, the static test should be carried out first to confirm and keep the equipment and test software working normally and meet the sailing test conditions;

(2) The ship leaves the berth and sails at a constant speed of 5 knots to point A (near the VTS control center). During this period, the communication ability and receiving sensitivity of different channels are tested by broadcast test;

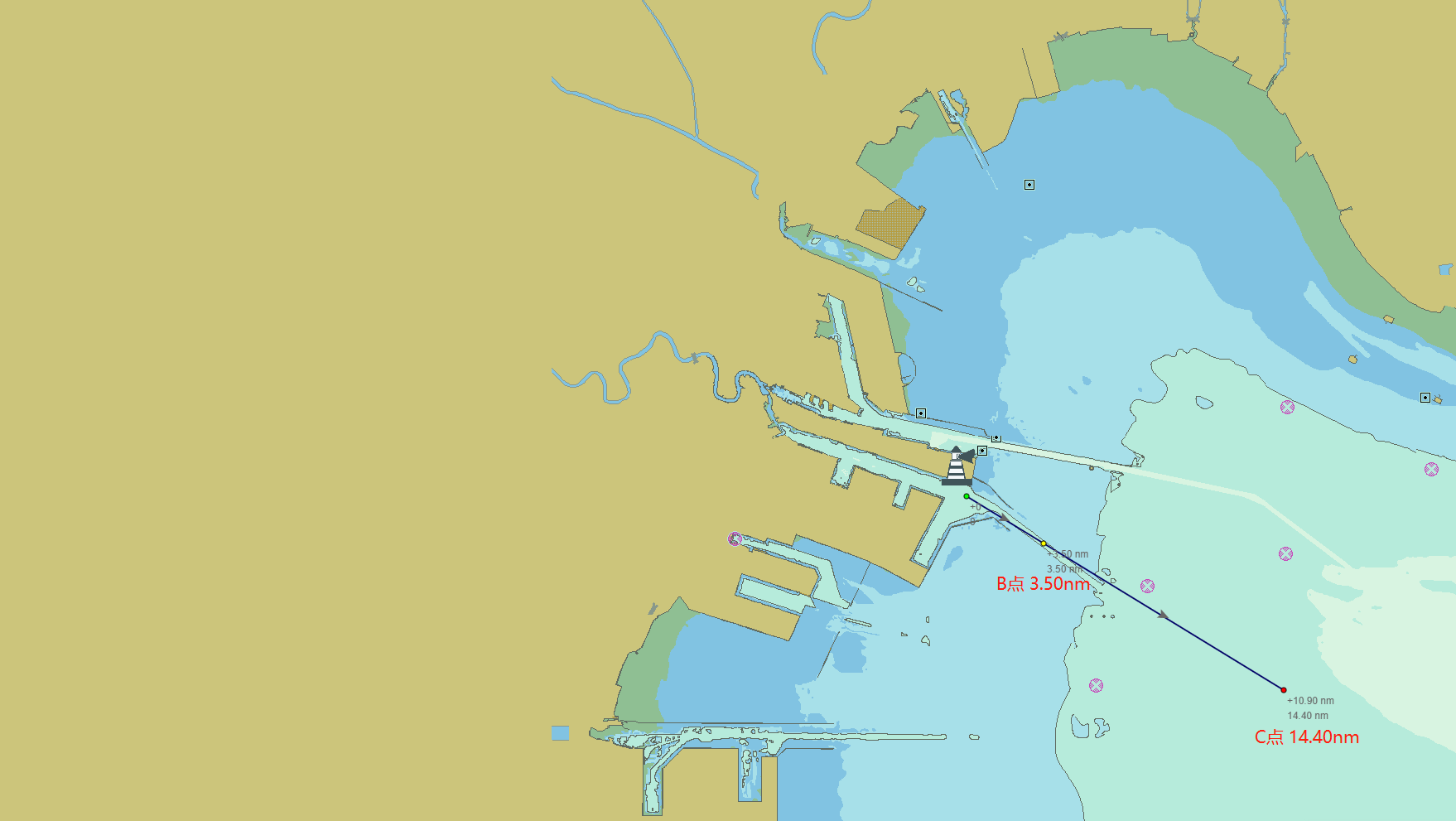
(3) After arriving at point A (near the VTS control center), the ship sails along the channel of Tianjin port at a constant speed of 5 knots to point B (3.5nm). During this period, the communication ability and receiving sensitivity of different channels are tested by broadcast test and addressing tests;

(4) The ship sailed to point C (14.4nm) at a constant speed of 9 knots. During this period, the communication ability and receiving sensitivity of different channels were tested by broadcast test and addressing test;

(5) During the operation of the ship, broadcast test and addressing test are carried out continuously to detect the communication ability and receiving sensitivity of different channels;

(6) After the completion of the ship operation, the ship will return according to the original plan, repeat the process of point C, point B and point A, and continue the test.

Shore station equipment deployment and ship route are shown in the figure below.



Point A: VTS control center

Point B

Point C

Figure 7 Shore station equipment deployment and ship route

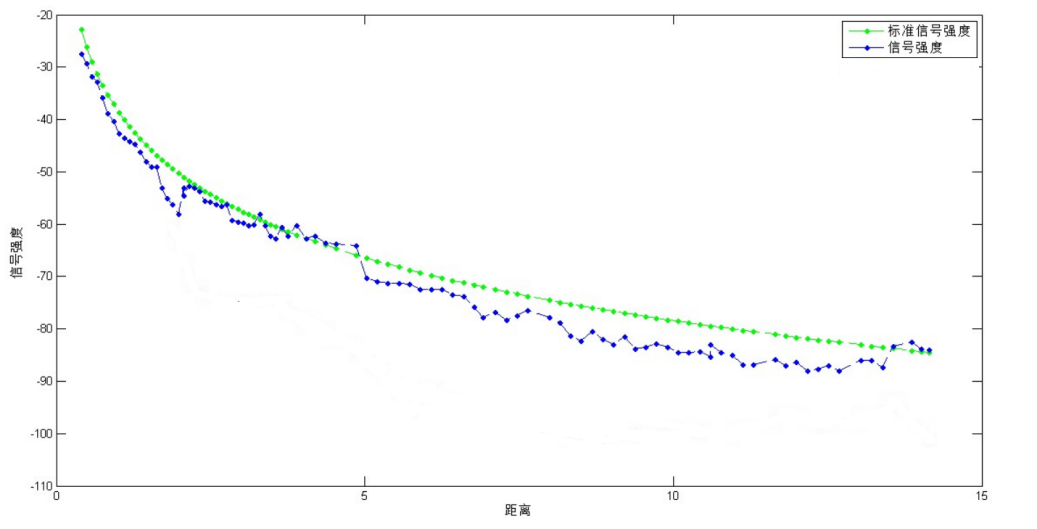
* + 1. **TEST RESULTS AND ANALYSIS**

The test results are shown in the following table:

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Distance** | **AIS channel** | | | **ASM** | | | **VDE** | | |
| **Sent** | **Received** | **PER** | **Sent** | **Received** | **PER** | **Sent** | **Received** | **PER** |
| **1** | **3.5nm** | 376 | 301 | 19.90% | 254 | 238 | 6.30% | 200 | 199 | 0.50% |
| **2** | **9nm** | 361 | 285 | 21% | 235 | 218 | 7.20% | 200 | 200 | 0% |
| **3** | **14.4nm** | 474 | 355 | 25.10% | 240 | 222 | 7.50% | 200 | 193 | 3.50% |

According to the test results, the PER of ASM and VDE channels is less than 20%, which meets the requirements in the standard. The PER of AIS channel is slightly higher than that required in the standard. The main reason is that the selection of time slot for some AIS equipment installed on ships did not in strict accordance with the standard when sending messages, resulting in the phenomenon of time slot conflicts. In case of time slot conflicts, only AIS messages with stronger signal strength can be correctly demodulated at the receiver side.

The received signal strength on the voyage test and theoretical calculation results are shown in the following figure:



Distance

Signal Strength

---Standard signal strength

---Test signal strength

Figure 8 The received signal strength on the voyage test and theoretical calculation results

The green line represents the function of the received signal strength and transmission distance of the theoretical VDES equipment calculated according to the calculation formula of marine ship loss, and the blue line represents the received signal strength and transmission distance of the VDES equipment during the navigation test, which is about 3 dB different from the theoretical curve. On the one hand, the difference is caused by the maritime multipath, on the other hand, it is caused by the fluctuation of the transmitted signal. According to ITU-R M.2092 standard, the transmitter power is allowed to have a deviation of ± 1.5dB, which is close to the normal deviation range.

Limited by the influence of the ship's operating distance, the actual communication limit distance could not be measured in this test, but the theoretical maximum communication distance can be calculated.

The antenna height of shore station is 70 meters, and that of ship station is 15 meters. The transmitting signal frequency is about 162MHz. It can be calculated that the communication distance between AIS channel and ASM channel is 92km, namely 60 nautical miles. For VDE channel, when transmitting with 100kHz bandwidth and 16QAM modulation mode, the theoretical communication distance of VDE channel can be calculated as 31 nautical miles if the sensitivity is calculated according to the standard - 96dB.

When using 100KHz bandwidth and QPSK modulation, the longest theoretical communication distance of the VDE channel can be calculated to 50 nautical miles if the sensitivity is 104dB.

Whereas, when using 25KHz bandwidth and QPSK modulation, the longest theoretical communication distance is 70 nautical miles if the sensitivity is 110dB.

1. **Conclusion**

The VDES project construction and related test results in the North China Sea Area verify VDES technical features and functions provided by ITU-R M.2092-0 proposal:

1. VDES shore-based base stations and ship-borne equipment referring to the technical characteristics of ASM channels and VDE-TER in the proposal can basically meet the technical specifications of the proposal.
2. The system is designed by the channel partitioning, signal acquisition, modulation and demodulation, and other technologies provided by the Recommendation, while its functional application refers to the access control,data link service and link management technologies provided by the Recommendation. Through testing, it can be understood the operation performance of VDES system under these technical characteristics;

(3) The equipment and application software systems developed by VDES verify the technical feasibility of protocols in link layer, network layer and transport layer;

(4) Verifying that the received signal strength of the VDES device is consistent with the theoretical value at different distances;

(5) Under the same circumstances, communication distance of VDE channel in high transmission rate mode is lower than that of low transmission rate mode.

(6) Irregular AIS ship-borne equipment has great influence on AIS channel.

1. **Demand for committees**

We sincerely invite the Committee and interested parties to consider the information and data provided by this proposal, and to provide guidance for the later optimization, construction, promotion and application of the VDES demonstration system in the North China Sea Area.

We sincerely invite the Committee and interested parties to make use of the system platform built by the project to carry out multi-party cooperation to further test and research the application of VDES system.

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Leave open if uncertain [↑](#footnote-ref-2)