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| From: ENG Committee | EM1-5.1.3.8 |
| To: ENAV Committee | October 22 |

LIAISON NOTE

VDES R-Mode

# Introduction

The ENG committee received an input paper ENG16-3.1.3.9 on “Technical implementation of VDES R-Mode”. The paper provides suggestions on technical implementation of VDES R-Mode, including ranging signal, slot management, navigation messages and recommended receiver design. The purpose of this paper is also to summarize the technical implementation of VDE-TER R-Mode with regards to IALA G1158 and furthermore, to introduce ASM-TER R-Mode related to the development of the “IALA Guideline on Implementation of R-Mode on MF and VHF frequencies”.

The ENG Committee has reviewed the input paper and felt that the document should also be of interest to the ENAV Committee in particular, sections 3.2, 4.2.5, 4.2.6 and 4.2.7 which contain information that could be relevant to the existing Guideline G1158 and could also be considered for a revision of this Guideline.

The ENG Committee welcomes the opportunity to continue the overall standardization of R-Mode together with the ENAV committee.

# Action requested

The ENAV Committee is requested to:

* Note the information provided in Annex 1.
* Consider a revision of Guideline G1158 based on the information provided in Annex 1.

ANNEX 1

**Technical implementation of VDES R-Mode**

# Summary

The Ranging Mode (R-Mode) of the existing maritime communication system is an economical land-based positioning system. It is a backup for Global Navigation Satellite Systems (GNSS) and also an important support for e-Navigation. This proposal gives suggestions on technical implementation of VDES R-Mode, including ranging signal, slot management, navigation message and recommended receiver design.

The purpose of this paper is to summarize technical implementation of VDE-TER R-Mode in IALA G-1158 and also introduce that of ASM-TER R-Mode, to support the <IALA Guideline on Implementation of R-Mode on MF and VHF frequencies>.

1. **Background**

In order to reduce the impact of GNSS service interruption on maritime navigation and ensure the safety of ships, ships should be equipped with both space-based and land-based positioning and navigation systems. R-Mode is a low-cost land-based positioning and navigation system that utilizes the existing maritime radio communication infrastructure.

The AIS Ship Autonomous Navigation System (AAPS) project in China (2012-2015) initially realized the positioning function of the AIS R-Mode, and conducted theoretical research on the VDES R-Mode in 2016-2017. Based on the above research, the Project of VDES R-Mode Testbed (2018-2020) has built an R-Mode testbed in the Yellow and Bohai Sea. At present, research to improve the positioning accuracy is being done.

This paper is to give suggestions on the technical implementation of VDES R-mode based on the results of the AIS/VDES R-Mode Testbed Project.

1. **Discussion**

## Technical Background

The existing VDES R-Mode guideline (IALA G-1158) sets out guidance for authorities to setup VDES R-Mode and developers to design a VDES R-Mode receiver or transmitter. The document builds up on the stakeholder and system requirements and introduces the VDES R-Mode architecture. It defines the needed PHY and MAC layer essentials based on the ITU-R M.2092-1 [1]. Further, the document provides support on how VDES R-Mode is setup in the VDES framework, the additional navigation data and outlines potential performance expectations under different conditions and environments [2].

IALA G-1158 introduces the R-Mode physical layer, link layer and application layer based on the VDE-TER signal. This document summarizes technical implementation of VDE-TER R-Mode in IALA G-1158 and also introduces that of ASM-TER R-Mode. Relevant contents are in the Annex, which can be supplemented to Section 4.2 of < IALA Guideline on Implementation of R-Mode on MF and VHF frequencies> being drafted.

This document also recommends an ASM-TER R-Mode receiver design for reference.

## Recommended ASM-TER R-Mode receiver

The ASM-TER R-Mode receiver structure shown in Figure 4 can be used for communication and ranging at the same time. The signal received by the antenna first passes through the RF front-end circuit and obtains the digital IF signal after down-conversion and A/D sampling, which is connected to the IF circuit. π/4 QPSK demodulation for ASM messages and correlation processing for TOA are carried out at the same time in the IF circuit. The processor uses the demodulated ASM message for normal data communication, and uses the TOA measurement value for positioning.



1. Block diagram of ASM-TER R-Mode receiver structure
2. This ASM-TER R-Mode receiver design can be supplemented to appropriate section of < IALA Guideline on Implementation of R-Mode on MF and VHF frequencies> being drafted.

# References

1. ITU, Recommendation ITU-R M.2092-1, Technical characteristics for a VHF data exchange system in the VHF maritime mobile band, 2022.
2. IALA, Guideline G1158-VDES R-Mode, Edition 1, 2020.

# Action requested of the Committee

Discuss the proposal and include the Annex A into the IALA Guideline on Implementation of R-Mode on MF and VHF frequencies.

ANNEX A

Section 4.2 of <Implementation of R-Mode on MF and VHF frequencies>

# Technical Implementation of R-Mode

## VDES R-Mode

### **Technical Background**

The existing VDES R-Mode guideline (IALA G-1158) sets out guidance for authorities to setup VDES R-Mode and developers to design a VDES R-Mode receiver or transmitter. The document builds up on the stakeholder and system requirements and introduces the VDES R-Mode architecture. It defines the needed PHY and MAC layer essentials based on the ITU-R M.2092-1 [1]. Further, IALA G-1158 provides support on how VDES R-Mode is setup in the VDES framework, the additional navigation data and outlines potential performance expectations under different conditions and environments.

IALA G-1158 introduces the R-Mode physical layer, link layer and application layer based on the VDE-TER signal. This document summarizes technical implementation of VDE-TER R-Mode in IALA G-1158 and also introduces that of ASM-TER R-Mode.

* + 1. **VDE-TER R-Mode Signal**

The ranging sequence is a concatenation of two known sequences to customize the required performance based on the given scenarios. The scenarios considered are:

* 1. Shorter distances with high SNR between shore station and vessels ()
  2. Longer distances with lower SNR between shore station and vessels ()

Figure 1 describes how both sequences are concatenated as part of the data message of a VDE-TER slot based on the factor.

VDE-Slot: 26.67 ms

Gold sequence

Alternating sequence

…

…

1. Example of sequence concatenation

Both sequences are concatenated, and factor γ defines the portion of the whole sequence used by parts of the Gold code sequence. The remainder is filled up by symbols of the alternating sequence.

The first part of the ranging sequences is based on the pi/4-QPSK modulation alphabet and alternates its constellation points. The second part of the ranging sequence is a Gold code with 1877 symbols. Further details on ranging sequences are given in IALA guideline G-1158.

* + 1. **VDE-TER R-Mode Link Layer**

The link layer of VDE-TER enables VDES R-Mode together with precise timing at the transmitter. The VDES R-Mode base station broadcasts the ranging sequence via the Ranging Channel once per second at a known and defined time instance with link-ID 37.

In the link layer the ranging sequence shall be transmitted by the Ranging Channel and utilizes the shore-to-ship short message (#93). The navigation data shall be communicated by a shore originated broadcast message.

* + 1. **VDE-TER R-Mode Navigation message**

The VDES R-Mode receiver requires additional information, termed navigation data, to determine the distance to the base station utilizing the received ranging sequence.

The navigation data is transmitted via VDE-TER from a VDES base station with the link-ID 11 every minute. It accommodates information to allow a cold start and determines a position latest after 16 minutes. Up to 16 VDES R-Mode base stations have a unique ID within the local VDES R-Mode network. Each ID of a VDES R-Mode base station is linked to clock and delay correction data and the coordinates of the phase centre of the VDES R-Mode base station.

As shown in Table 1, the navigation data comprises of the R-Mode System Time (RMST) and conversion data to UTC, and clock information of four VDES R-Mode base stations. Therefore, the relevant clock information of up to 16 VDES R-Mode base stations is received latest every 4 minutes. The coordinates of the phase centre of specific VDES R-Mode base station. Therefore, the coordinates of all relevant VDES R-Mode base stations in the network are broadcast with an update rate of 16 minutes maximum.

If the VDES R-Mode network has less than 16 VDES R-Mode base stations, the system provider may repeat the clock and delay correction information more frequently.

1. *Ordering and number of bits of the navigation data*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Bit order in the message | Purpose |  | Bits per stations | Total bits of network |
| 1 | RMST | 1 | 32 | 32 |
| 2 | RMST to UTC conversion | 1 | 99 | 99 |
| 3 | Clock and delay corrections + ID | 4 | 26+4 | 120 |
| 4 | Validity and signal health status in the network | 1 | 3 | 3 |
| 5 | Coordinates of phase centre of transmitter antenna + ID | 1 | 71+4 | 75 |
| 6 | γ factor of concatenated ranging sequences | 1 | 2 | 2 |
|  | **Total bits** |  | 241 | 331 |
|  | Spare bits for future use |  |  | 101 |
|  | **Total bits (link-ID 11)** |  |  | **432** |

Further details on VDE-TER R-Mode navigation data are given in IALA guideline G-1158.

* + 1. **ASM-TER R-Mode Signal**

The general slot format of ASM-TER is shown in Table 2. Each slot consists of six parts: Ramp up, Training sequence, Link ID, Data, Ramp down and Guard. The ramp-up time for power change from -50 dBc to -1.5 dBc is 416 microseconds (us), to provide spectral shaping and reduce interference, and the modulation is not specified for the ramp up. The training sequence is described in detail in the next paragraph. The Link ID based on π/4 QPSK modulation follows the training sequence to define the channel configurations. The Data payload with its Cyclic Redundancy Check (CRC) is interleaved encoded scrambled and bit mapped. The ramp down time from full power to −50 dBc should be no more than 416 us. The rest Guard time is for delay and jitter.

1. *ASM-TER General Slot Format*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Ramp up** | **Training Sequence** | **Link ID** | **Data** | **Ramp Down** | **Guard** |
| 0.41 ms | 27 symbols  (1 1111100110101 0000011001010) | 16 symbols | Data with CRC | 0.41 ms | 0.83 ms |

The training sequence of ASM-TER is a 27-symbols sequence with π/4 QPSK modulation. The last 26 symbols are barker13 code (1 1 1 1 1 0 0 1 1 0 1 0 1) and inverted barker13 code (0 0 0 0 0 1 1 0 0 1 0 1 0) with ideal autocorrelation, which can be used to detect the weak target signal submerged in noise. The ideal autocorrelation of the double Barker 13 code can be used for ranging. In the training sequence, the symbol “1” maps to π/4 QPSK symbol “3” (1 1), and the symbol “0” maps to π/4 QPSK symbol “0” (0 0).



1. *Bit Mapping for π/4 QPSK and Phase Alternating of the Training Sequence*

Figure 2 shows the bit mapping for π/4 QPSK used in ASM-TER, and the phase alternating of the training sequence. There are 4 possible phase variations of ± π/4 and ±3π/4 when the symbol changes. Since there are only "11" and "00" in the training sequence, without "01" and "10", it has only four kinds of phase alternating as shown in Figure 2. The first the symbol “1” of the training sequence maps to π/4 QPSK symbol “3” (1 1), is mapped to the constellation defined by the point (1+j)/√2; the next symbol “1” is mapped to the constellation defined by point 1+0j (shown in blue in Figure 2); the next symbol “1” is mapped to the constellation defined by point (-1-j)/√2 (shown in green in Figure 2) and so on.

According to the structure of the training sequence shown in Table 2, if the first symbol of the link configuration ID is 0, as received sequence shown in Figure 3, the correlation value is the maximum when the local reproduced 26 symbols exactly match the received signal. Because *ms* is 26 and *ns* is 0, where *ms* is the number of matched symbols and *ns* is the number of mismatched symbols. The correlation value is the minimum when the locally re-produced 26 symbols are 1 symbol time *Ts* earlier or later than the received signal, for *ms* is 13 and *ns* is 13, as shown in Figure 3. Therefore, the navigation data can be transmitted via ASM-TER with the link-ID 54 to make the first symbol 0. (It is recommended here to reserve the last 10 link IDs those are 54-63 for ASM)



1. *Number of matched symbols ms and number of mismatched symbols ns*
   * 1. **ASM-TER R-Mode Slot Map**

There are two transmission modes of the ASM-TER R-Mode ranging signals can be used, synchronous mode and asynchronous mode. The synchronous transmission of ranging signals will reduce the error of the receiver clock jitter and the error of time different of arrival (TDOA) caused by ship motion. However the complexity of synchronous transmission is higher and the ranging performance of the weaker signal would be affected.

* + - 1. **Synchronous Transmission**

The ASM-TER R-Mode ranging signal transmission from the VDES base station can be carried out in the way shown in Figure 3. The transmission modes of all base stations are divided into three types: A, B and C:

• Type A base stations continuously transmit two slots on ASM1, and then stop one slot;

• Type B base station transmits one slot on ASM2 first, and after a slot interval, transmits one slot on ASM1;

• Type C base stations stop for one slot, and then continuously transmit two slots on ASM2.

The base station management system first defines the base station as A1, B1, C1; A2, B2, C2. At the beginning of the transmission period (for example 6 seconds), transmit ASM ranging signals in order of A1 B1 C1; B1 C1 A2, C1 A2 B2, A2 B2 C2.....

Therefore, if the transmission period is 6 seconds, it allows 225 base stations to transmit the signals once in the period. The base station capacity of ASM-TER R-mode network can be up to 225. If the transmission period is extended, the capacity of the base station can be increased correspondingly, but the location update rate of the user receiver will be decreased accordingly.



1. *ASM ranging signal synchronous transmission slot diagram*
   * + 1. **Asynchronous Transmission**

The asynchronous transmission rule of the base station ranging signal can be as shown in Figure 5. The base station management system firstly numbers the base stations according to the position as No1, 2, 3, 4, 5, 6..... At the beginning of the transmission period (for example 6 seconds), the ranging signal is transmitted on the same channel (ASM1 or ASM2) in sequence in the order of numbers.



1. *ASM ranging signal asynchronous transmission slot map*

Similarly, if each transmission period is 6 seconds, the base station capacity of the ASM-TER R-Mode network is 225.

* + 1. **ASM-TER R-Mode Navigation message**

The navigation data is transmitted via ASM-TER from a VDES base station with the link-ID 54 every 6 seconds. Scheduled broadcast ASM message (#10 for example) can be used to transmit ASM-TER R-Mode navigation message. Its training sequence can be used to obtain ranging values. The navigation message is as shown in Table 3. It comprises of the source station information, UTC time, and differential correction parameter.

1. *ASM-TER R-Mode navigation message format*

|  |  |  |
| --- | --- | --- |
| Parameter | Length(bit) | Comment |
| Message ID | 4 | Identifier for Message 10;  always 10 |
| Source ID | 32 | MMSI number of source station |
| Reserved | 4 | Set to 0 |
| Shore station longitude | 32 | Longitude in 1/10 000 min |
| Shore station latitude | 32 | Latitude in 1/10 000 min |
| UTC year | 14 | 1-9999 |
| UTC month | 4 | 1-12 |
| UTC day | 5 | 1-31 |
| UTC hour | 5 | 0-23 |
| UTC minute | 6 | 0-59 |
| UTC second | 6 | 0-59 |
| Synchronization States | 2 | 0.GNSS valid；  1.GNSS short-term invalid；  2. GNSS long-term invalid，synchronized with reference station；  3. GNSS long-term invalid and is not synchronized with the reference station。 |
| Slot number /Communication status | TBD | TBD |
| Differential correction parameter | TBD | Set to 0 |
| Reserved | TBD | Set to 0 |
| Total | 352 |  |